COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

April 1951

Courtesy of D. K. Park

Start of fire in boiler at Titus Station, Metropolitan Edison Co.

COMBUSTION

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Vol. 22 **No. 10**

April, 1951

Feature Articles

Editorials

Departments

COMBUSTION publishes its annual index in the June issue and is indexed regularly by Engineering Index, Inc.

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Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16
A SUBSIDIARY OF COMBUSTION ENGINEERING-SUPERHEATER INC.

Joseph V. Santry, President; Charles McDonough, Vice-President; H. H. Berry, Secretary and Treasurer

COMBUSTION is sent gratis to engineers in the U. S. A. in charge of steam plants from 500 rated boiler horsepower up and to consulting engineers in this field. To others the subscription rate, including postage, is $3 in the United States, $3.50 in Canada and Latin America and $4 in other countries. Single copies: 30 cents.

Publication Office, Easton, Pa. Issued the middle of the month of publication.

Acceptance under Section 34.64, P. L. & R., authorized by United States Post Office.

CCA

Printed in U. S. A.

COMBUSTION

Editorials

Freedom of the Technical Press

Speaking recently before the Ohio Newspaper Association, Secretary of Commerce Sawyer touched upon publicity versus security. He pointed out that information useful to our potential enemies is more likely to result from careful examination and collating of official statements than from spies within our midst. Such statements, he said, are often attributable to the desire of certain public officials to break into print, sometimes with startling announcements, or to their fear of being criticized when it is discovered that information has been withheld.

Within his own department, Mr. Sawyer has established a service aimed at helping the public guard voluntarily against the release of technical information that might endanger national security. Use of this service, he emphasized, is not mandatory; rather it is designed to furnish one point in the government to which a patriotic citizen can turn when in doubt.

It will be recalled that during World War II censorship of the technical press was established, and although it was demonstrated that the editors of technical magazines could be depended upon to exercise proper judgment, delays and inconvenience were often imposed by the censors, through a desire to play safe in view of their own limited knowledge. In some cases their actions became almost ludicrous. Although there is as yet no declared war, certain power plants and marine installations have been placed in a restricted category and there are already some indications of unwarranted restrictions on items that could have no conceivable relation to defense.

It would seem that Secretary Sawyer's plan is preferable providing, of course, that those charged with its functioning are competent to advise intelligently.

Specialists in Corrosion and Decay

Two relatively unpublicized problems encountered in the design and operation of the steam power plant were the subjects of technical papers at recent engineering meetings. About the only common ground for the two problems is that they are concerned with the degeneration of component parts of a power plant, though by vastly different mechanisms. What they are indicative of is the high degree of specialized knowledge that occasionally may have to be called upon.

A paper delivered before the 1951 Conference of the National Association of Corrosion Engineers was entitled "Cathodic Protection at Steam-Electric Generating Stations." Considering that a central station may have an installed capacity of several hundred thousand kilowatts and an annual generation ranging into billions of kilowatt-hours, it challenges the imagination to realize that its structure constitutes a galvanic cell with the power of self-destruction through corrosion. By contrast to transmission lines leaving the station at an alternating-current potential in excess of 100,000 volts, the plant itself is the electrical equivalent of a dry cell having a direct-current potential on the order of one volt. Unless steps are taken to neutralize this galvanic cell, serious corrosion of the power-plant structure may take place. That is where cathodic protection and the specialized knowledge of the corrosion engineer enter the picture.

At the recent ASME Spring Meeting in Atlanta a paper was presented on "Deterioration of Wood in Cooling Towers," bringing to attention a second problem calling for the services of specialists not commonly associated with the steam power field. Few engineers have ever heard of *Poria monticola* or *Lenzites trabea*, but those fungi play an important part in the decay of redwood. Thus in making an investigation of cooling-tower deterioration it was necessary to engage the services of a pathologist as well as a chemist. Through collaboration of these specialists, experimental data were acquired to explain the mechanism of deterioration.

St. Lawrence Power

Once again the long-discussed St. Lawrence Seaway and Power Project has come to the fore. In general, the line-up for and against the proposal is, as in former years, with the Federal and State Administrations, reinforced by various public power groups and Great Lakes shipping interests, as strong advocates, opposed by the eastern railroads, certain sections of the coal mining industry, including the United Mine Workers, shippers along the northeastern seaboard and much of the electric utility industry.

This time the additional argument that it is an essential defense measure has been introduced in testimony recently given before Congress. In this Charles E. Wilson, the Defense Mobilizer, appears as a new convert principally on the grounds that the seaway would facilitate bringing Labrador ore to the steel mills; also that the United States' share of the proposed power development would help meet the requirements of the expanded aluminum and electro-metallurgical industries.

Undoubtedly Mr. Wilson's opinion will carry considerable weight with Congress, but many are likely to question the project's defense value in view of the estimated time required for completion, as compared with an equivalent power generating capacity in steam plants. Moreover, some have argued that the seaway might actually prove to be a liability in the event of actual warfare.

Models in Power Plant Design

ALTHOUGH the employment of models in engineering work has long been practiced, both as to individual pieces of equipment and as a means of depicting the layout and general appearance of an entire installation, in the majority of cases they represent a *fait accompli* for the satisfaction of the owner who generally employs them for exhibition purposes.

Less often do we find models playing a dominant rôle throughout the various stages of design; yet when one considers the complexity of many modern power plants, as well as the architectural and operating considerations to be satisfied, the utility of models becomes apparent. Moreover, their use often results in substantial savings in both time and expense of drafting changes. A short observation of a model may be the equivalent of long hours of blueprint study.

A firm that has carried out the model idea to a high degree is Ebasco Services, Inc.—well-known New York engineering firm which has been responsible for the design of many outstanding power plants and which, it may be recalled, has long led in the application of outdoor and semi-outdoor construction for power plants.

A recent visit to the offices of this company disclosed a veritable museum of power plant models and layouts. But they are by no means museum exhibits in the generally accepted sense. They are utilitarian and many are being used currently in conjunction with design work. They comprise extensions to existing stations and many new stations, including one that will have an initial capacity of more than 650,000 kw. Only when these working purposes have been served are the models shipped to customers or displayed in a special room for possible later consideration when plant extension may be contemplated.

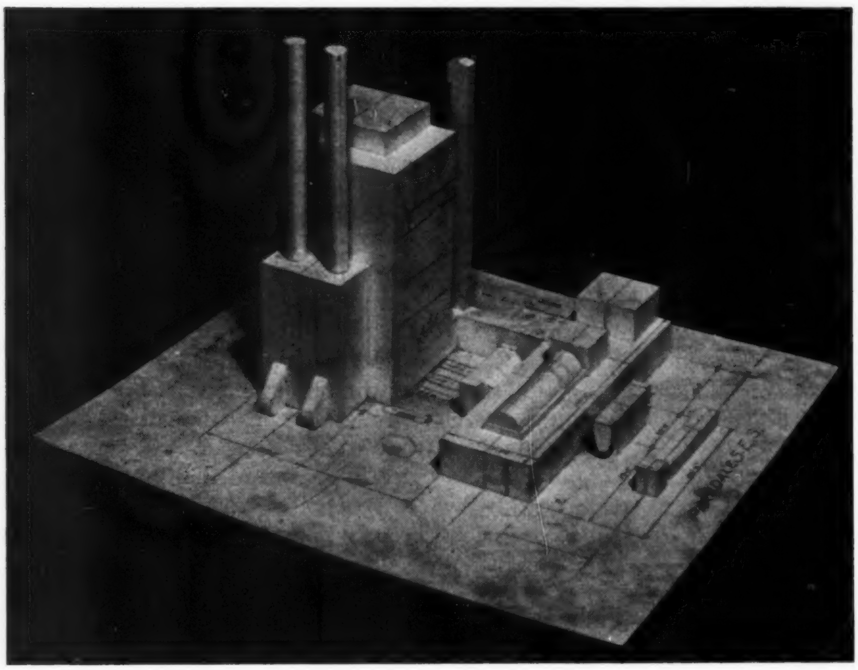
Three types of models are employed. The first, which is usually to a small scale, is relatively simple and essentially of the block type. It serves the preliminary purpose of affording the customer and his engineers a general impression of how the completed plant will look; of meeting space requirements; of affording means of placing component parts in most advantageous locations; and of viewing extensions relative to existing structure.

The second type of model represents a bird's-eye view of the completed installation and affords a far better understanding of an installation than is possible from a batch of blueprints. It is the type of model that is useful in giving an overall conception of the plant to financiers and boards of directors.

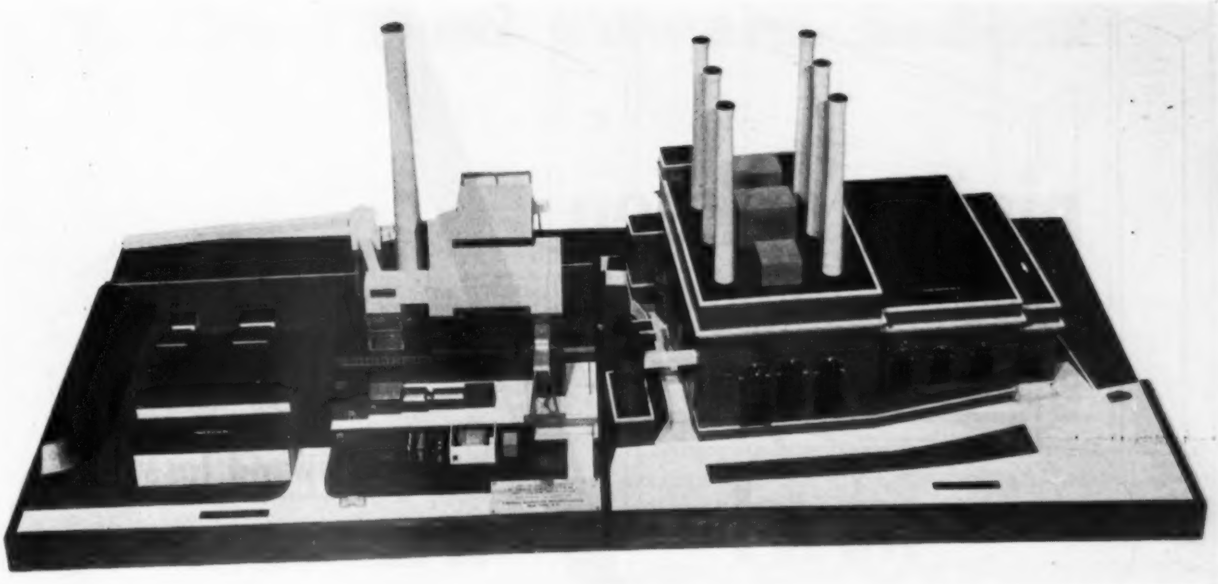
The third type serves primarily as a working model. Often made to a scale of one half inch to the foot or larger, it contains all piping runs with prescribed clearances. A miniature operator formed to scale size can be shifted to various positions to determine accessibility of working areas. Sometimes this type of model precedes a detailed piping layout, while in other cases the model serves for checking and thus avoids expensive field changes. In many cases it is practically impossible to modify high-pressure, high-temperature piping in the field, and if interferences are found it would be necessary to return pipe to the fabricator, involving considerable expense and time. However, the use of a model to check piping drawings obviates the necessity by translating the piping as installed in the model into revised piping drawings. For a complex piping system this procedure may effect large savings in design and construction cost.

The models are generally made of wood or plastic material.

Another unique feature that has been developed by Ebasco is a combined control panel and bench board measuring eight feet in length and containing all essential meters and gages in miniature size. This permits the operator to exercise complete control from a single position in front of the board. Because of its relative simplicity this control panel may be operated in times of emergency by comparatively inexperienced personnel.



Block-type model used in preliminary design of semi-outdoor plant located in the Southwest



Model of Glenwood Power Station of Long Island Lighting Co., Glenwood No. 1 is on the left, the 100,000-kw extension is in the center, and Glenwood No. 2 is on the right

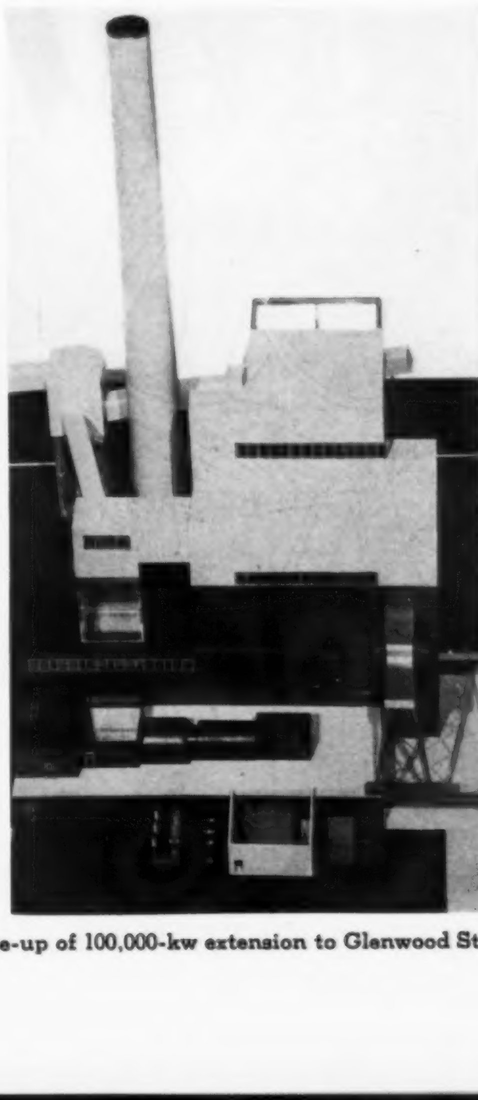
Indications on the simplified control board are given by retransmission of original intelligence. This avoids the potential danger encountered when high pressure steam and air connections are run directly to the control board. All wiring for these control boards is done in the factory of the manufacturer.

Ebasco has developed a full scale mock-up of the combined control panel and bench board. For each project instruments are located on the mock-up in the manner desired for the finished station. A photograph is made of the arrangement of instruments and this serves as a part of the specification for the control panel.

As an example of the engineering uses to which the models are put, a single station will be cited. The Long Island Lighting Company has had a steam-plant installation at Glenwood Landing on the north shore of Long Island since 1905. The original plant, Glenwood No. 1, had a total capacity of 10,500 kw in three turbine generator units operating at 200 psig. It was of low-level construction and initially contained stoker-fired boilers which have since been removed and the space occupied by evaporators.

In 1928, construction was started on Glenwood No. 2 which is a high-level station containing two 75,000-kw and one 20,000-kw turbine-generators. This section has six steam generating units which are fired with oil or pulverized coal.

Recently it was decided to make another addition, Glenwood No. 3, this time using a semi-outdoor design instead of the fully enclosed construction employed for the first two plants. To make room for the latest extension, which will be a 100,000-kw single boiler-turbine-generator reheat unit operating at 1450 psig, 1000/1000 F, a part of Glenwood No. 1 is being dismantled. Since a residential area is adjacent to the site, it was considered desirable to see how the power-plant addition would fit into the existing terrain, particularly as the available area is limited, with a highway on one side and the harbor on the other side. A model to the scale of $^1/_{16}$ in. to the foot was constructed to aid in visualizing the appearance of the 100,000-kw extension. This replaced an architectural perspective that ordinarily would have been prepared to show the proposed construction. After the original model was completed, several conferences were held and a number of modifications were made in the projected design. These were later incorporated in the model.



Close-up of 100,000-kw extension to Glenwood Station

The Trend Toward Reheat

By H. G. EBDON

Vice Pres., Combustion Engineering-Superheater, Inc.

In this paper before the Midwest Power Conference the author reviews the application of the reheat cycle from the 1920's, when a limited number of installations were made, through the post war period culminating in orders for 116 reheat units of over 12 million kilowatts aggregate capacity from 1945 to the present. Of these, 82 units representing 9,690,000 kw were placed on order in the past 15 months. The advantages of reheat are discussed and the performance of some recent installations cited.

IN recent years there has been an increasing interest in reheat, as evidenced by the number of reheat boilers and turbines purchased by the utility companies and by the many papers presented before engineering meetings and reported in the technical press. The arguments for reheat, though they have become fairly well established, merit repetition at this point.

Reheat offers the following advantages:

1. For the same initial steam conditions, reheat makes possible the achievement of a 4 to 6 per cent gain in cycle economy for large turbines in which the steam is reheated to approximately the initial temperature and at the most advantageous pressure.
2. The average moisture content of steam during expansion is less, and there is an increase in available energy. For the same rating less steam flow is required.
3. Because of the reduction in steam flow, the condenser, feedwater heaters and related piping may be reduced in size, resulting in a smaller investment. The savings thus obtained compensate for the increased cost of the reheat turbine and boiler.
4. Where cooling water supply is limited, the reduced condenser heat rejection of the reheat cycle enables the installation of from $7^1/_2$ to 11 per cent more capacity in reheat than in non-reheat units.

POST WAR REHEAT UNITS

January 1st 1946 to January 1st 1950

Name	Station	No. of Units	Throttle Pressure	Primary Temperature	Reheat Temperature	KW-MAX Capability
Wisconsin Electric Power Co.	Pt. Washington	3	1450	950	950	80,000
Boston Edison Co.	Edgar	2	1450	1000	1000	81,250
Appalachian Electric Power Co.	Sporn	4	2000	1050	1000	150,000
Indiana Michigan Electric Co.	Twin Branch	1	2000	1050	1000	150,000
Indiana Michigan Electric Co.	Tanners Creek	2	2000	1050	1000	150,000
Niagara Mohawk Power Corp.	Dunkirk	2	1450	1000	1000	100,000
Niagara Mohawk Power Corp.	Oswego	1	1450	1000	1000	100,000
Metropolitan Edison Co.	Titus	2	1450	1000	1000	75,000
Dayton Power & Light Co.	Hutchings	2	1450	1000	1000	62,500
Rochester Gas & Electric Co.	Russell	1	1450	1000	1000	62,500
New England Power Co.	Salem	2	1450	1000	1000	75,000
Pennsylvania Power Co.	New Castle	1	1450	1000	1000	100,000
Duke Power Co.	Lee	2	1250	950	950	100,000
Public Service Co. of Northern Ill.	Waukegan	1	1800	1000	1000	125,000
New York State Gas & Elec. Co.	Goudey	1	1450	1000	1000	75,000
Public Service Elec & Gas Co.	Sewaren	1	1550	1050	1000	125,000
Union Electric Co.	Meramec	1	1250	950	950	125,000
Central Hudson Gas & Elec. Co.	Danskammer	1	1700	1000	1000	62,500
Consumers Power Co.	Erie	2	1450	1000	1000	100,000
Jersey Central Power & Light Co.	So. Amboy	1	1700	1000	1000	62,500
Cincinnati Gas & Elec. Co.	Clermont	1	1450	1000	1000	100,000

POST WAR REHEAT UNITS

January 1st 1950 to March 1st 1951

NAME	STATION	NO. OF UNITS	THROTTLE PRESSURE	PRIMARY TEMPERATURE	REHEAT TEMPERATURE	KW-MAX CAPABILITY
Central Illinois Public Serv. Co.	Hutsonville	2	1450	1000	1000	75,000
Duke Power Co.	Riverbend	2	1250	950	950	100,000
Duke Power Co.	New	2	1800	1000	1000	125,000
Niagara Mohawk Power Corp.	Albany	3	1450	1000	1000	100,000
Niagara Mohawk Power Corp.	Huntley	2	1450	1000	1000	100,000
Carolina Power & Light Co.	Goldsboro	1	1450	1000	1000	75,000
Carolina Power & Light Co.	Lumberton	:	1450	1000	1000	75,000
Long Island Lighting Co.	Glenwood	1	1450	1000	1000	100,000
Long Island Lighting Co.	Far Rockaway	1	1450	1000	1000	100,000
Consolidated Edison Co.	Astoria	2	1800	1000	1000	150,000
Consolidated Edison Co.	East River	1	1800	1000	1000	150,000
Virginia Electric & Power Co.	Chesterfield	1	1450	1000	1000	100,000
Virginia Electric & Power Co.	Gilmerton	1	1450	1000	1000	100,000
Philadelphia Electric Co.	Delaware	2	1800	1000	1000	150,000
Philadelphia Electric Co.	Crombie	1	1800	1000	1000	150,000
Philadelphia Electric Co.	Schuykill	1	1800	1000	1000	150,000
Illinois Power Co.	Hennepin	1	1450	1000	1000	75,000
Illinois Power Co.	Wood River	1	1450	1000	1000	100,000
American Gas & Electric Co.	Kanawha	2	2000	1050	1000	200,000
American Gas & Electric Co.	Muskigum	2	2000	1050	1000	200,000
Florida Power & Light Co.		2	1450	1000	1000	75,000
Dayton Power & Light Co.	Hutchings	2	1450	1000	1000	62,500
Ohio Edison Co.	Niles	2	1450	1000	1000	125,000
Detroit Edison Co.	Marine City	2	1800	1000	1000	125,000
Detroit Edison Co.	Zug Island	2	1800	1000	1000	125,000
Commonwealth Edison Co.	Ridgeland	1	1800	1000	1000	125,000
Rochester Gas & Elec. Co.	Russell	1	1450	1000	1000	62,500
Wisconsin Electric Power Co.	Oak Creek	2	1800	1000	1000	120,000
Metropolitan Edison Co.	Titus	1	1450	1000	1000	75,000
Public Service Elec. & Gas Co.	Kearney	2	2300	1100	1050	150,000
Southern California Edison Co.	Etiwanda	2	1800	1000	1000	125,000
Pacific Gas & Electric Co.	Contra Costa	2	1450	1000	1000	125,000
Pacific Gas & Electric Co.	Moss Landing	2	1450	1000	1000	125,000
Cleveland Electric Illum Co.	East Lake	2	1800	1050	1000	125,000
Tennessee Valley Authority	Plant A	4	1800	1000	1000	150,000
Tennessee Valley Authority	Plant C	4	1800	1000	1000	150,000
N.Y. State Gas & Electric Co.		1	1450	1000	1000	100,000
Cincinnati Gas & Electric Co.	Clermont	1	1450	1000	1000	100,000
Union Electric Co.	Meramec	1	1250	950	950	125,000
Connecticut Light & Power Co.		1	1450	1000	1000	75,000
Electric Energy Inc.	Joppa	4	1800	1050	1000	150,000
South Carolina Elec. & Gas Co.		2	1450	1000	1000	75,000
Wisconsin Power & Light Co.	Beloit	1	1450	1000	1000	75,000
Utah Power & Light Co.	Salt Lake	1	1450	1000	1000	75,000
Public Service of Indiana	Wabash	2	1450	1000	1000	100,000
Pennsylvania Power & Light Co.	Sunbury	1	1450	1000	1000	125,000
Jersey Central Power & Light Co.		1	1800	1000	1000	100,000
Kansas City Power & Light Co.	Hawthorn	1	1450	1000	1000	100,000
Rockland Light & Power Co.		1	1700	1000	1000	62,500

5. Regardless of initial steam conditions, the reheat cycle maintains a theoretical advantage over the non-reheat regenerative cycle.

6. The inherent greater efficiency of the reheat cycle contributes to the conservation of fuel reserves.

7. With the single boiler-turbine-generator arrangement there is no problem of complexity of operation. The reheat boiler is essentially a conventional high-capacity steam generator with an additional superheater section making up the reheater. Operation is no more difficult and requires no more personnel than a conventional non-reheat unit of similar capacity.

Early Reheat Installations

The first power plants employing the reheat cycle were placed in service in the 1920's. Among those pioneering

stations using reheat were Twin Branch, Philo, Crawford, Edgar, Columbia and Lakeside. Altogether there were about 40 turbine units aggregating a capacity of nearly 2,000,000 kw in the period between 1924 and 1930. Materials available during this period limited steam temperatures to 750 F and reheating offered an opportunity to improve cycle efficiency. Furthermore, difficulties were being encountered because of water erosion of low-pressure or exhaust-end turbine blades and reheating was an attractive means of reducing moisture content.

Increased Steam Temperatures

Metallurgical advances soon took place which permitted higher steam temperatures. In 1932 the Burlington Station went into operation with a steam temperature of 850 F and by 1937 Logan was in service using 925 F steam. Operating pressures increased with higher temperatures and many low-pressure plants were "topped" by high-pressure units, though at no time was interest completely lost in reheat. At least four reheat installations were made during this period.

An important and historic reheat installation is the Port Washington Station of the Wisconsin Electric Power Company. Planning for this station began in 1929, but due to the depression the first unit was not placed in commercial service until November 22, 1935. It was the first large single boiler-turbine-generator installation. Rated at 80,000 kw, its throttle steam conditions were 1230 psig and 825 F. A second unit of essentially similar design was placed in operation on October 27, 1943, followed by Unit No. 3 on October 5, 1948; Unit No. 4 on August 25, 1949; and Unit No. 5 on December 15, 1950. Pressures and temperatures at Port Washington had increased as the later units were added, with Unit No. 5 operating at 1465 psig and 950 F. As is well known in the utility industry, the Port Washington units have had a phenomenal availability record. The station ranked as the most efficient in the United States (and in the world) on a Btu per net kilowatt-hour basis for about twelve years, a record of outstanding continuing performance.

Post-War Expansion

At the end of World War II there were mixed feelings within the utility industry concerning the rate at which generating facilities should be expanded. Although there were relatively few central-station units placed in service during World War II, many utility officials believed that the wartime electric load would fall off rapidly with the coming of peace. If such were to be the case, it was felt that expansion and replacement of generating facilities could proceed at a rather leisurely rate. An example of this viewpoint is found in the following quotation from an article which appeared in the August 1945 issue of the *Edison Electric Institute Bulletin:*

"It seems indisputable that, with all due allowance for rapid conversion to civilian production, the utility industry will experience during the first two years after V-E Day a rather drastic reduction in kilowatt-hour power sales and a substantial reduction in kilowatt peak demand.

"This implies from the purchasing viewpoint a reduction in fuel purchases, some relief from an early need for constructing new generating capacity and the probable release from service and return to inventory of substation equipment. This opinion applies to the utility industry as a whole and is not valid for an individual company whose sales pattern differs substantially from that of the composite electric utility industry."

As is well known, the anticipated drop in electric load did not materialize. In fact, electric consumption in 1948 was 25 per cent greater than that of the peak war year. This meant that it was necessary to add generating equipment as rapidly as possible. Getting new units into service was primary, and most companies took advantage of wartime advances in the power plant art without going to extreme steam conditions. It might be generalized that the "first wave" of post-war central stations was designed with only casual consideration being given to the reheat cycle. Actually, the first post-war reheat unit was Port Washington No. 3, ordered in 1945, and followed by three units for the American Gas & Electric System in 1946 and 1947. Two of these units were for Sporn Station and the other for Twin Branch. In the latter year another unit was purchased for Port Washington as well as one for the Edgar Station of the Boston Edison Company.

In designing many of the post-war stations the assumption was made that fuel prices would not continue to rise, or, if so, at a decreasing rate. This did not occur and efficiency of operation as reflected in fuel consumption became an even more important criterion than initial station cost. Reheat afforded an attractive way of realizing a substantial return on a slightly increased investment in station cost.

Increasing Demand for Reheat

By 1948 the single boiler-turbine-generator arrangement had become standard practice and the generally accepted steam cycle at the time was 1250 psig and 950 F. A reduction in net heat rate of almost 1000 Btu was available with the reheat cycle at 1450 psig, 1000 F resuperheated to 1000 F and other systems found that with existing fuel prices the added cost of reheat could be justified. Niagara Mohawk, Rochester Gas & Electric, Dayton Power, Metropolitan Edison and Duke Power started the trend.

A total of sixteen reheat units were purchased in 1948 with an aggregate capacity of 1,597,500 kw. Ten other utility systems went to reheat in 1949, adding twelve units with a total capacity of 1,130,000 kw. Rated maximum capability of these units ranged from 62,500 kw to 150,000 kw.

There was much discussion at power meetings during this two-year period as to the economics and merits of reheat. There were many who felt they would be sacrificing availability due to complexity of operation, which would more than offset the improved heat rate. Others thought system load was not large enough or load factors were too low to consider reheat. The industry seemed to be about equally divided in its opinion on the issue of reheat.

In 1950, the trend toward adoption of reheat by utility systems, large and small, became unmistakable. Eighty-two units aggregating 9,690,000 kw have been placed on order from January 1, 1950 to March 1, 1951. One manufacturer reported that nearly 70 per cent of the

utility business booked during that period was for reheat installations. Twenty-four additional utility companies purchased reheat units for the first time in these fifteen months. This made a total postwar addition of 116 reheat units and 12,102,500 kw of capacity.

Of the fifteen largest private utility companies, excluding those with 100 per cent hydro resources, fourteen had reheat units either on order or in service at the beginning of 1951. More than half of these companies adopted reheat during 1950.

The Central Hudson Gas & Electric Corporation, with a 1950 system peak of only 135,000 kw was the first of the small systems to "go reheat" when in July 1950 they purchased a unit with a maximum capability of 62,500 kw. This unit will go into service this fall.

Geographical Distribution

Reheat installations are not confined to any one geographical area. Of the eight electric power supply regions established by the Federal Power Commission, Region 1 in the northeastern United States has the largest number of reheat units, 37 with a total turbine capability of 3,797,500 kw. Included in this group are major power stations in the Boston, New York, Philadelphia and Buffalo areas. Region II ranks second with 30 reheat units aggregating 3,900,000 kw in western Pennsylvania, West Virginia, Ohio, and parts of Kentucky, Indiana and Michigan. Region IV which includes Illinois, Wisconsin and part of Missouri is third with 22 units and a total of 2,580,000 kw. This includes 1,200,000 kw to supply the Atomic Energy Commission project near Paducah, Ky. Quite surprising is the strong showing of Region III in southeastern U. S., which has 19 units and 2,000,000 kw of turbine capability.

Size of Units

While the average size of the post-war units is slightly over 100,000 kw maximum capability, it is interesting to note the number that are much smaller. There are nine units of the 50,000/62,500 kw range and 23 of the 60,000/75,000 size. With the growth in system load there seems to be little reason to design units smaller than 50,000/62,500 kw. There is, however, an increasing demand for still larger units and the Kanawha and Muskingum plants of American Gas & Electric Corporation which have recently been laid down, will have a net output of 200,000 kw each.

Units in Service

The first post-war unit to be placed in service was Port Washington No. 3 in October 1948. Port Washington No. 4, Edgar, Sporn and Twin Branch units started up at about the same time in August 1949. These were followed in 1950 by Sporn No. 2 (June), Dunkirk No. 1 (October) and No. 2 (November), Russell No. 1 of Rochester Gas & Electric Company (November), and Port Washington No. 5 (December).

Hutchings No. 3 of Dayton Power & Light Company was put on the line January 1951 and on February 5, 1951, Titus No. 1 of Metropolitan Edison was cut in. Tanners Creek No. 1 also went into service in February 1951.

Thirteen reheat units have been put into successful operation in the past two and one half years, five of which have been in service for more than one and one half years. The operating experience with all of these units has been such as to dispell any fears of operating difficulties.

TYPICAL SYSTEMS USING REHEAT

	NUMBER	KW CAPACITY	1950 PEAK LOAD
LARGE SYSTEMS			
American Gas & Electric Corp.	11	1,850,000	2,386,000
Tennessee Valley Authority	8	1,200,000	3,125,000
Niagara Mohawk Power Corp.	8	800,000	2,271,300
Duke Power Co.	6	650,000	1,390,000
Wisconsin Electric Power Co.	8	600,000	713,000
Philadelphia Electric Co.	4	600,000	1,779,000
Consolidated Edison Co.	3	450,000	2,724,000
Public Service Elect. & Gas Co.	3	425,000	1,417,200
INTERMEDIATE AVERAGE SYSTEMS			
Dayton Power & Light Co.	4	250,000	325,000*
Long Island Lighting Co.	2	200,000	340,900
Rochester Gas & Elec. Co.	2	125,000	201,700
SMALL SYSTEMS			
Central Hudson Gas & Electric Co.	1	62,500	135,000
Rockland Light & Power Co.	1	62,500	

In the beginning, there was some anxiety as to starting up and shutting down procedures, emergency trip-outs, steam pressure prior to opening of throttle valves, protection of reheater metals during no-flow periods, length of time required to bring the unit on the line and the problem of controlling two steam temperatures. All of these conditions have been met with success.

The engineers and operators are unanimous in their opinions that reheat units can be brought on the line or shut down as fast as non-reheat units and react to emergency trip-outs in the same manner. There has been no overheating of reheater elements and both primary and reheat temperatures are kept under full control.

The units at Dunkirk have operated up to 110,000 kw. The Russell unit at Rochester averages 68,000 kw output with peaks as high as 72,000 kw. At Sporn, the average output is 156,000 kw with peaks up to 163,000 kw. While the net heat rate at Sporn for 1950 has not been published as yet, it is expected to be close to 9400 Btu per kwhr.

SUMMARY			
	JAN. 46 to JAN. 50	JAN. 50 to MARCH 51	TOTAL
No. of Units	34	82	116
Maximum capability – KW	3,417,500	9,690,000	13,107,500
No. of Utility Systems	18	24	42
UNIT SIZE			
62,500	5	4	9
75,000	10	13	23
100,000	9	19	28
125,000	3	25	28
150,000	7	17	24
200,000	–	4	4
THROTTLE PRESSURE			
1250#	3	3	6
1450#	23	40	63
1800#	1	33	34
2000#	7	4	11
2300#	–	2	2
PRIMARY STEAM TEMPERATURE			
950F	6	3	9
1000F	20	67	87
1050F	8	10	18
1100F	–	2	2

Summary

In developing procedures for starting up and for normal operation of reheat units, it was necessary for the manufacturers of boilers and turbines to gain a closer understanding of one another's problems. The resulting close cooperation has made possible improved overall unit design. Extensive efforts have been made to develop standard reheat boiler-turbine-generator units, thereby materially reducing the differential capital cost between reheat and non-reheat units.

Looking back over the years, the utility industry can feel justly proud of its reduction in the national coal rate from 3 lb per kwhr in 1920 to 1.22 lb per kwhr in 1950. However, it is well to recall that most of this gain took place in the first ten years of the period and that since 1942 the improvement in national coal rate has been but 0.08 lb per kwhr.

In terms of thermal efficiency the ten most efficient steam plants in the United States in 1949, as reported by the Federal Power Commission, ranged from 10,437 Btu per kwhr to 11,442 Btu per kwhr. Some idea of the amount of improvement that is still possible may be had by comparing those figures with the approximate rate of 9400 Btu per kwhr for the Sporn Station in 1950 and the calculated 9000 Btu per kwhr for the new 1100-F reheat units at the Kearny Station of Public Service Electric and Gas Company.

Considerable credit is due to the utility managements who had the courage to "go reheat" in the early post-war years. They were the ones who were convinced that they could master any operating problems which might arise. With the primary objective of reducing fuel costs to a minimum, the five per cent saving offered by the reheat cycle was something worth going after. It was these engineers who were responsible for the trend toward reheat. The success of their efforts can be measured by the 9,500,000 kw of reheat capacity ordered in the past fifteen months.

Overfire Air Jets in European Practice

In view of the widespread application of overfire air, both here and abroad, and its importance as an aid to good combustion and smoke prevention, it is believed the following notes will be welcomed as presenting a brief history of the subject, a discussion of the design principles involved, nozzle arrangements, amount of overfire air required and a review of results attained in European practice. Appended is a very complete reference of foreign literature on the subject.

By WILHELM GUMZ

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OVERFIRE air, correctly applied, is now accepted as the most effective, simple and inexpensive means of improving combustion conditions in a stoker-fired boiler furnace. Overfire air jets will eliminate or reduce heat losses from incomplete combustion, unburned gas and unburned carbon, visible smoke and slagging. Furthermore, they will cut requirements of combustion space and thus enable fuel rates to be increased without impairing boiler efficiency. Overfire air jets tend not only to compensate for carelessly operated or inadequate combustion equipment, but they will also improve results in modern stoker furnaces operated at high rates. Thus, they serve not only to promote smoke abatement, but also lower boiler-house expense.

The use of overfire air has received broad attention in America through research projects sponsored by Bituminous Coal Research, Inc.,† the results of which work have been made available in technical publications and in a practical application manual (8, 9)‡.

Inasmuch as a large amount of the available information is in foreign literature, this survey has been prepared of material published in Europe on overfire air, so as to make it readily accessible to American engineers.

Historical Review

Overfire or secondary air has been used for nearly as long as boiler furnaces have been used. Back in 1697, Papin is supposed to have employed overfire air, and in 1795, W. Thompson was granted a patent relative to it. In 1855, a French memorandum was issued on smoke abatement, clearly conceiving overfire air as the most suitable way for improving combustion (30). In 1899, the Society of German Engineers (VDI) sponsored a prize-winning contest for treatises on smoke abatement. One such prize treatise became a well-known (now outdated) German book on boiler furnaces (23), and presents a large variety of devices for secondary-air supply and for air-control. In a discussion of R. F. Davis' paper on air jets (6), W. Gregson states that "in the days of the coal-fired (British) Navy all the ships were equipped with overfire air jets." This was also true for many stationary installations.

In those days, however, little was known about the mechanics of the air jet and the combustion process, and as the old smoky hand-fired furnace was displaced by mechanical grates, the former practice of injecting overfire air came to be disregarded, and its beneficial influence was neglected. Although mechanical stokers, in comparison to hand-fired units, have definitely improved combustion conditions, still, they have not eliminated emission of volatile gas constituents and the gasification products of the solid carbon, as evidenced by the presence of flames far above the fuel bed.

The finer details of the combustion process were not subjected to investigation until refined methods had become known, and not until there was an increased interest in fuel savings and increased ratings of stoker furnaces arising from the fuel shortage after World War I. At this time, there were greater demands for steam and larger steam-generating units. Specifically, the performance of the traveling grate stoker was thoroughly tested by means of gas analyses in and above the fuel bed, and a number of papers were published on the investigations (34, 43, 57, 64, 65). A new concept of combustion finally developed thereafter, from the realization that combustion is mainly a physical result of mixing fuel and combustion air. Rummel (51), investigating the combustion of gases, reduced this concept to the short formula: "mixed = burnt," and Marcard (35–37), Fritsch (13), Rosin and co-workers (48), and others (21) stressed a new aspect of the combustion process in considering the furnace space of a stoker-fired boiler as being mainly a "mixing device." These ideas, although not at all revolutionary, have promoted fuel and combustion research and have largely contributed to progress in furnace and boiler design.

Development of the traveling grate stoker, which is the prevailing type of industrial stoker in Europe from the low-rated chain grate into the modern compartment stoker without, or with only a very short, front or rear arch, revealed the fact that stratification of combustion gases had become a serious problem, and that the necessary height and space requirements of high-rated archless traveling grate stokers offset part of the reduction in maintenance cost and the advantage of the increased fuel rates. This development called for further investigation of the gas flow in large combustion chambers, and overfire air jets made a widespread comeback as the most effective way to improve combustion conditions above the fuel bed, and to control gas mixing and gas combustion within a restricted space and for a limited residence time.

† The assistance and encouragement of Bituminous Coal Research, Inc., in the preparation of this paper are acknowledged.

‡ Numbers pertain to references at end of article.

Jet Mechanics

Before some of the results of these investigations and further developments are summarized, a concept of air-jet action will be briefly discussed as a background for properly selecting equipment and evaluating operating conditions.

When an air jet leaves a nozzle, it has a velocity of

$$u = \sqrt{2_g \frac{\kappa}{\kappa - 1} p_1 v_1 \left[1 \left(\frac{p_2}{p_1} \right)^{\kappa - 1/\kappa} \right]} \tag{1}$$

The symbols in the above equation are more or less self-explanatory, κ being the adiabatic expansion coefficient,

$$\kappa = c_p/c_v, \tag{2}$$

which is about 1.4 for air. Subscripts 1 and 2 refer to the pressure before and after the nozzle, respectively; or, in the case of an overfire air jet, to the pressure in the plenum chamber, and in the furnace, respectively. The kinetic energy of this jet of air decreases rapidly as soon as it leaves the nozzle, partly because of the expansion of the gases into space, and partly because of the mixing in the jet with surrounding gases which have to be accelerated to the jet velocity. Numerous investigations with fairly identical results are to be found in the aerodynamic literature, notably those of Tollmien (63), Schlichting (56), Zimm (67), Kuethe (32), and others (55). The central linear velocity of the jet at x (distance from the nozzle tip), according to Davis (6), is

$$\frac{u_x}{u_0} = \frac{K_1}{(x/d) + K_2} \tag{3}$$

where constants $K_1 = 8.4$, $K_2 = 2$ and d = nozzle diameter.

Equations (1) and (2) already give much information on jet characteristics, and the following conclusions regarding the practical result can be drawn:

> The length of penetration of a jet, x, is a function of the initial air velocity, u_0, and the nozzle diameter.
>
> The initial velocity of the jet depends largely upon the pressure, p_1, and to some degree on the temperature.

Apparently the jet or nozzle diameter, or to express it in a more perceptual way—the relative surface of an air jet—is largely responsible for decay of velocity, and, thus, for the length or depth of penetration. Thin jets are weak and ineffectual because they have shallow projection and are dissolved quickly. This condition sets a lower limit for nozzle diameters. Since a circular jet has a minimum surface, the circular nozzle is preferred to any other shape, such as oval, rectangular flat slots, etc., unless, of course, structural conditions require use of those forms.

The influence of temperature, which determines v_1 in Equation (1), has aroused some discussion as to whether hot or cold air should be used. Some authors (11) have contended that cold air injected into a hot gas promotes turbulence; others have found no noticeable difference in the use of cold or of preheated air (31). Actually, the difference in the quoted experimental work (38) was slight, 30 C as against 150 C; therefore, the difference in initial velocity would be

$$\sqrt{(150 + 273)/(30 + 273)} = 1.18,$$

or 18 per cent, which is scarcely within the limits of experimental evidence. The existence of a large difference of gas and air viscosity has been emphasized; nevertheless, the rapid mixing of the air with the surrounding hot gases equalizes temperature differences so quickly that this factor would not exert much influence. There is no doubt that preheating the air is the cheapest way to increase its kinetic energy, a fact which becomes obvious in jet-type pulverizers. Experimenters, such as Smirnov and co-workers (62), effected improvements by using preheated air. The advantage of quicker ignition of the combustible gases and less cooling effect by overfire air jets has been emphasized by A. R. Mayer (38–40). In agreement with these considerations, the use of preheated air has been highly recommended (18, 19, 21) even to the extent of using a higher temperature for the secondary air than for the primary air when the size of the installation justifies an additional air heater, and when local conditions can be satisfied by a simple technical solution with no excessive duct work.

Apart from the investigation of air jets, the aerodynamics of gas flow in furnaces and boilers (12, 35, 37, 54) has attracted many workers, and basic tests on mixing of parallel or of crossing fluid streams have been conducted in model experiments (51, 53, 54), which are helpful in understanding and even in calculative treatment of the problems involved.

Mixing of Gas Streams

Whatever stoker system or secondary-air device is being considered, the mixing of two gas streams always appears to be the main problem. Mixing of parallel streams of gases is a very slow process. There is always stratification in boiler furnaces, and it is known that sometimes irregularities in a fuel bed will persist throughout the entire gas path of the boiler system. It may be worth while to discuss some of the results of the basic investigations conducted in furnace design. Schiegler's experiments (54) indicate that two parallel streams moving with two different velocities u_1 and u_2 will have a lateral mass exchange expressed as "mixing width," y, after a distance of flow, h, which roughly can be expressed by

$$y/h = 0.31 - 0.3095(u_1/u_2). \tag{4}$$

A better correlation of Schiegler's experimental data is possible by Equation (5):

$$y/h = 0.27 - 0.2654(u_r)^{0.5}, \tag{5}$$

where

$$u_r = (u_1/u_2) - 0.26,$$

differentiating between a laminar region below $u_1/u_2 = 0.26$, with a constant y/h of 0.27, and a turbulent, or possibly transition region above $u_1/u_2 = 0.26$, according to Equation (5).

Rummel's investigations (51) cover a wide range of operating variables and flow patterns, partly made possible by adopting a hydrogen tracer method (0.5 per cent H_2 in air). Some of the results which are of practical interest in this connection may be summarized as follows:

The absolute velocities of two gas streams, traveling in parallel with the same velocity, have only a very limited effect upon the mixing.

Two jets of different velocities improve mixing, in accordance with Schiegler's findings.

Air streams or jets at an acute angle improve the mixing considerably, as shown in Fig. 1 from reference 21.

The kinetic energy of two intermixing streams should be equal, otherwise they only bend or penetrate without causing essential mixing.

The last-mentioned finding calls for jet velocities, as compared with common gas velocities prevailing in boiler furnaces as indicated in Fig. 2.

Rydberg (53) has conducted his experiments in a 11.8-in. tube, blending air into a stream of producer gas (and measuring flame length) under various directions, angles, different types of slots and baffles, etc. His

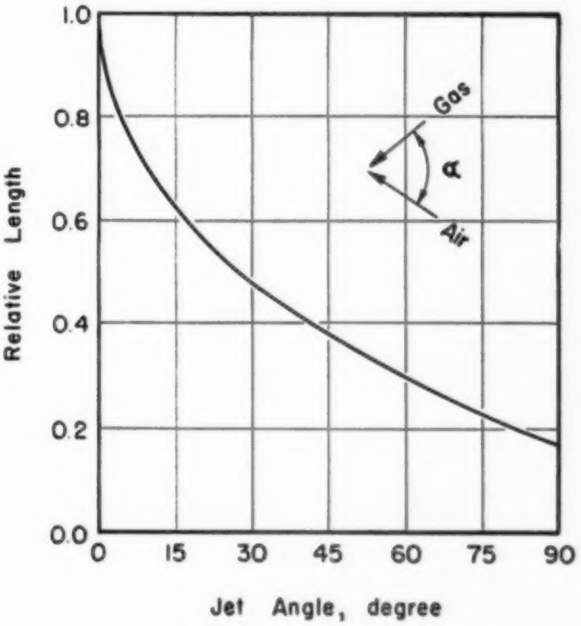

Fig. 1—Flame length as a function of the angle between air jet and gas jet (ref. 21)

findings summarized are that: a high energy consumption (pressure drop) does not necessarily warrant good mixing. Secondary air should be introduced preferably by as much splitting of gas and air streams as possible, which results in a better mixing effect with a minimum energy consumption. This suggestion refers to ducts of the size as investigated and cannot be generalized, inasmuch as a certain depth of penetration requires a definite minimum of initial velocity and jet diameter, and the effect of velocity cannot be substituted by a larger number of smaller jets. However, the importance of an adequately narrow spacing should be emphasized. As an additional measure, Rydberg considers contraction of the gas stream during or after mixing advisable.

Amount of Overfire Air

The amount of overfire air necessarily depends upon various conditions, the type of fuel fired, the type of stoker used, the average excess air applied, the available air pressure and the load. Although high-volatile coal may release more gases during devolatilization, the quantity of secondary air is by no means directly proportional to the volatile matter in the coal. Fuels of very low volatile content, such as anthracite or low-volatile bituminous coal, require overfire air as well as do high-volatile coals, because the gases emanating from the fuel bed are, to some extent, gasification and not only devolatilization products. It is not so much the deficiency of air, but rather the uniformity of air distribution; and not so much the admission of air, as the intensive mixing, that require the application of the jets. Even steam jets contributing nothing directly to combustion, would result in a similar effect. However, steam is usually too expensive and, therefore, is not recommended so long as air can do the same or a better job. Hence, the emphasis is on pressure, velocity and depth of penetration, as the factors which determine the lower limit of air quantity. The upper limit is more or less dictated by the requirement of effective cooling of the grate by the balance of primary air, and by the fact that the specific fuel rate is a direct function of the primary air which converts the solid fuel into the gaseous state. A percentage range of 4–6 was considered by Mayer (38–40); that is, 4 per cent for the lower limit and 6 per cent for heavy boiler load. Koessler recommends 7 per cent (31), although good results were reported by Schultes (58) with 5 per cent at sufficiently high pressures, and 10 per cent is taken as a good average. Some experiments have been run with as much as 25 to 30 per cent, but these are evidently cases where other factors, principally pressure, were unsatisfactory. Mostly, the upper limit may be as high as 12 to 15 per cent. The success may be hampered, in some cases of inadequate equipment, by difficulties in air distribution due to loose boiler settings or leaking air boxes, which cause a high proportion of "leakage air" and restrict the amount of additional air that is possible without too much dilution of the flue gases. Such furnace defects, however, need repairing whether overfire air is applied or not—so that failures due to excessive leakage do not detract from the inherent advantage of overfire air applied under right conditions.

The higher the air pressure and the higher the excess air, the lower the percentage of overfire air. Low-pressure systems, to be effective, may require even higher percentages than those recommended above. The requirements of a higher percentage of volatile matter in the fuel are preferentially balanced by higher pressures rather than by increased amounts of secondary air.

Plenum-Chamber Pressure

The most important step, and invariably the most frequent cause of failure, is the application of plenum-chamber pressure to achieve a desired projection and to give a mixing effect at the required places, i.e., all over the depth and length of the combustion chamber. The necessary pressure, therefore, is primarily a function of size of the combustion chamber and of the fuel rate. Methods for determining the pressure have been presented by several authors (6, 18, 19, 21, 44), who mainly draw fluid-flow trajectories by graphical summation of the air-jet velocity taking into account its constantly decreasing value, and the gas-flow vector generally directed straight upward. Since the quantity of gas flow-

ing through the combustion chamber is in proportion to the fuel rate, although mostly unevenly distributed, the resultant flow direction will be represented by a curve bending from the direction of the nozzle position into a perpendicular one. The decreasing jet velocity causes an increasing deflection of the original jet by the unaltering gas stream. A moderate-velocity jet is unable to penetrate the mass of flue gases; it is bent sharply and flows as an air blanket near the wall. Conditions are not improved, but are made even worse by the diluting effect of this air.

Admittedly, there is a more or less arbitrary assumption as to where the effective penetration ends; nevertheless, such an assumption has proved of practical use in determining the order of magnitude of the pressures or velocities required, and in corroborating the results of field tests. The graph shown in Fig. 2 gives the calculated data for a variety of average gas velocities in the combustion chamber, various depths of penetration, air pressures and temperatures, and can be used for an estimation of the required pressure for any given set of operating conditions (19, 21). It also clearly demonstrates the effect of pressure, temperature, nozzle diameter and size of the furnace space. Experimental results (38–40, 58) as well as calculations, show that pressures ranging from 8 to 16 in. water gage are required to achieve suitable mixing in average-size industrial or power-station boiler installations. A plenum-chamber pressure of 8 in. water gage has been recommended by Mayer (38–40) based on his experiments with a relatively small-capacity boiler, low-volatile bituminous coal, and with as little as 2.5 in. water gage at low loads. As much as 27 to 31 in. water gage has been considered necessary if the objective is to reduce the combustion chamber to half of its usual size. High-volatile bituminous coal, according to the same author, requires a 10 per cent higher air-jet velocity for effective mixing. However, no such statement is generally applicable, inasmuch as each individual case must be studied in particular before Fig. 2 will prove to be very useful in making definite recommendations.

The pressures mentioned offer an explanation of why many of the earlier installations either were complete failures or at least were not as efficient as expected. Taking in overfire air by natural draft, without any pressure, or using the primary air pressure to save an additional fan will succeed only in those rare cases where means other than the overfire air itself provide for intensive mixing. To reject the idea of overfire air jets because there have been many cases of such failures is unfair to a principle which proves its practical value whenever it is applied in a proper manner.

Nozzle Arrangement

The number of nozzles, their location and direction, are the most disputed factors in the use of overfire air jets. Without doubt, the type and size of furnace have some bearing on the subject; also the release of volatile gas and vapors is another important factor of nozzle arrangement, as it is frequently hampered by fire doors, arches, cooling tubes, etc., which thus impose certain practical limitations. The expected boiler load, including the maximum as well as the minimum load, should not be overlooked in designing the layout. In some instances, control has been suggested, either of each individual nozzle, or better yet, groups of nozzles so as to be able to respond to the widely varying load conditions, and to insure sufficient flow velocities at low loads (42). Although it is more expensive, such a flexible system offers the advantage of a more constant CO_2 content within the whole range of boiler loads. Mechanical (66) and electrical devices (24) have been suggested for automatic control.

Usually, the arrangement is made in one row or on one level; with a greater number of nozzles, several levels

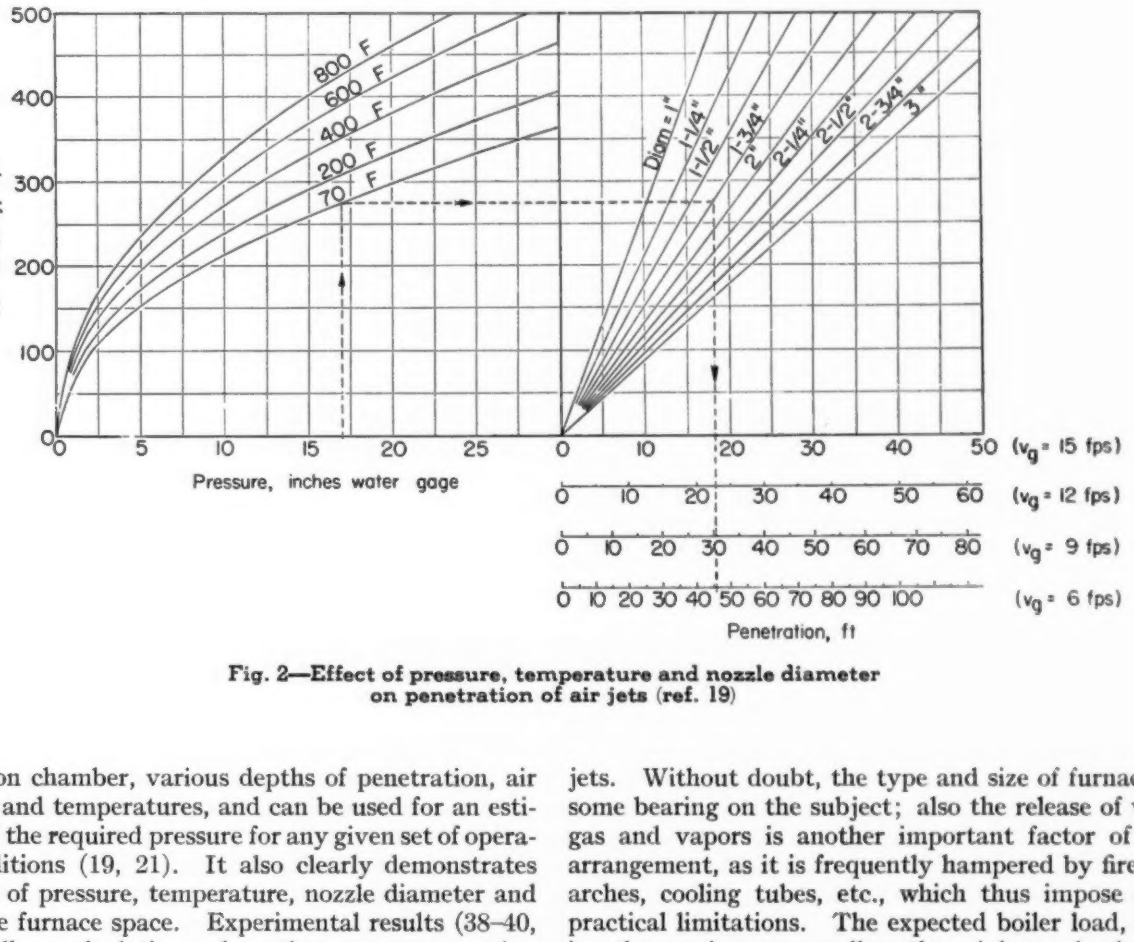

Fig. 2—Effect of pressure, temperature and nozzle diameter on penetration of air jets (ref. 19)

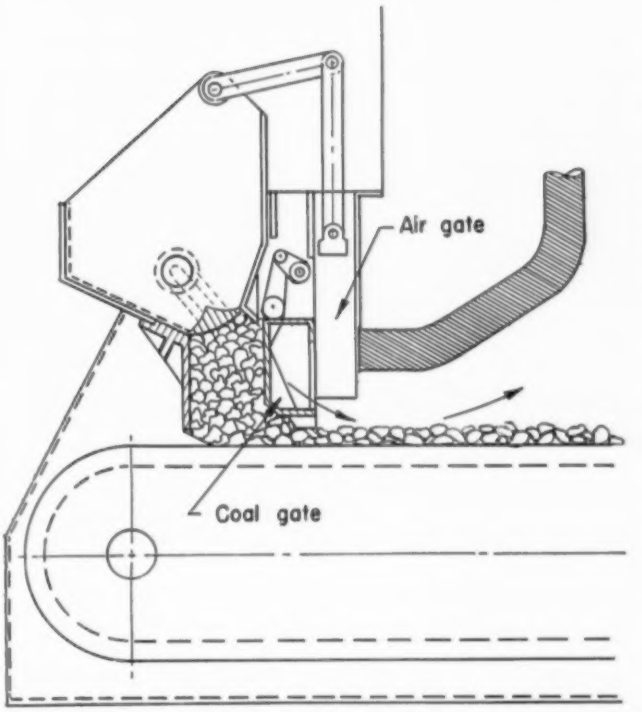

Fig. 3—Sketch of Bader System of overfire air injection applied to traveling grate stoker (ref. 19)

and a staggered arrangement have been recommended. Cleve (2) suggested the use of smaller and larger nozzle diameters alternately arranged to promote a more intensive turbulence. Smirnov and co-workers (62) recommended a staggered arrangement at both side walls for a whirling effect, but model tests, carried out by Rummel (52) indicated that such an effect is of doubtful use, and that impingement of nonstaggered jets seems to be a more promising arrangement (19, 21).

The number of nozzles is determined from the quantity of air to be injected, its pressure or air velocity, and the size of the nozzle. Usually, diameters between $1^{1}/_{4}$ and $2^{1}/_{2}$ in. are chosen, the maximum sometimes being limited by the space available between furnace wall tubes or by other structural factors. To some extent, such difficulties will be overcome by oblong or rectangular shapes, which, however, are not so desirable from other points of view. The shape of the nozzle, as shown experimentally (5), has no decisive influence upon the velocity, depth of penetration or effectiveness, and a simple, smooth pipe will achieve results equal to those of more elaborate and expensive forms.

The most popular jet arrangement with traveling grate stokers is in the front wall, directed downward 30 to 40 deg to the fuel bed. In larger furnaces, the side walls offer better possibilities, inasmuch as they require a shorter length of penetration and may be located closer to the fuel bed. Rapid ignition of the combustible gases while using as much furnace space or height as possible, for the mixing, is performed best by nozzles arranged as close to the fuel bed as practicable; this is especially important if the combustion chamber is water-cooled. There is even no harm, despite popular misgiving, in a downward-directed jet which impinges on the fuel bed, because the flow direction is diverted by the strong buoyancy of the furnace gases.

A deliberate impingement of the fuel bed is recommended by Pieper (46) in his design of a central heating boiler, resembling somewhat the well-known "smokeless stove" (33). Wherever gas velocities are low and furnaces are operated with very moderate draft, as in domestic heaters, it is more difficult to control gas flow and gas mixing, and many failures have been reported (47, 50). A full impingement with high-speed jets (75 to 225 ft per sec and 3 to 14 in. water gage pressure) is used in the "downjet burner" developed by the British Coal Utilization Research Association (29, 49, 60).

Spacing of the nozzles is another important factor. In many cases, spacing might be dictated by such design factors as spacing of water walls. Wherever spacing can be chosen independent of such limitations, it should be done in a manner to cover the grate surface as completely as possible. This inflicts another lower limit on the number of nozzles, as just a few nozzles will never perform satisfactorily except in very small furnaces. Spacing also depends upon the required length of penetration; a short length calls for narrower spacing, a large one for wider spacing. The wedge-shaped space unaffected by wider spaced jets could be covered by smaller jets between the larger ones, as suggested by Cleve (2, 3). Blowing from the corners to a circle in the center of the combustion chamber is inadequate because it omits large sections of the furnace from the mixing. One-foot spacing may be considered an average figure, but this again is no blanket statement covering all possible cases.

Other Systems

As a unique system to introduce air into a traveling grate furnace, Bader (19) suggested a horizontal slot immediately above the fuel bed over the entire width of the grate. Fig. 3 shows how this is done, either by a second gate behind the coal gate, or by a hollow coal gate serving as the plenum chamber. A relatively low pressure is required to admit air, and adequate gas mixing

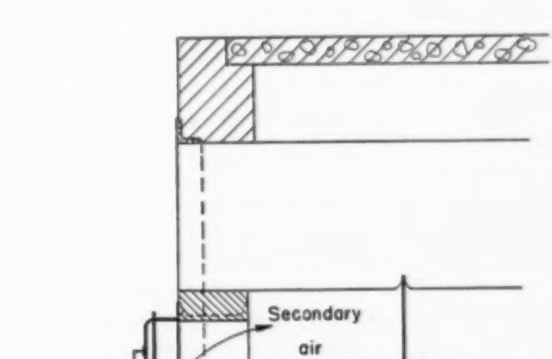

Fig. 4—Secondary air admission in a Lancashire boiler (ref. 17)

and elimination of smoke are achieved. Air flowing along the rough fuel bed promotes additional eddies which supposedly contribute to successful operation. A large front arch, was found in all older plants, helps to conduct the air to places where it is needed.

Other furnace types, where large openings and low pressures adequately serve the purpose of overfire air injection, are those associated with the Lancashire- and the Scotch-type boilers. The limited space above the fuel bed, the long mixing path along the fire tube and the mixing effect of the contraction exerted by the bridgewall, all give enough residence time for complete combustion to take place. Turbulence-promoting refractory guides are sometimes used to improve mixing, also to keep the tubes clean and thereby increase heat transmission. A similar effect of blanketing the fuel bed by overfire air may result from an arrangement of narrow-spaced nozzles in the bottom plate, as suggested by a Swedish manufacturer (16) and shown in Fig. 4. Another device based essentially on proper sizing and arrangement is the "smoke eliminator" developed by the Fuel Research Station and successfully used during and after the war by British merchant ships, and with hand-fired Lancashire boilers (13, 15).

Typical Results in European Practice

Hand-Fired Boiler Furnaces

The most spectacular results with overfire air will, admittedly, show up with the worst possible operating conditions. Thus, the hand-fired boiler furnaces, which are still widely in use in the smaller industrial plants as well as in some marine installations, commonly provide those conditions where any additional equipment or any extra effort on the part of the fireman will show immediate improvement. Fuel savings as high as 5.8 to 9.2 per cent (27, 28) have been reported from comparative trials.

The British Fuel Research Station during the war developed a "smoke eliminator" to protect coal-fired merchant ships from becoming easy prey of submarines. Tests on stationary plants as well as on board seagoing ships have shown that in ordinary commercial operation, with untrained Arab firemen, the performance of Scotch marine boilers with Howden forced-draft furnaces leaves ample room for improvement (14). Boiler efficiency was 66.8 per cent; heat loss by unburnt gases amounted to 8.2 per cent, and unburnt carbon (soot, smoke) was an estimated 2.5 per cent; and CO_2 content of the flue gas was 12.7 to 13.6 per cent, which figures would be considered very satisfactory under given circumstances. With the "smoke eliminator," which involved openings in the front top baffle of the furnace that were kept open for 8 to 11 min after the charging of fresh coal, and for 2 min after raking of the fuel bed, the boiler efficiency climbed to 70.7 per cent; the loss through combustible gas decreased to 4.2 per cent; and the soot loss dropped to 1.2 per cent. This improvement, although by no means completely satisfying, resulted in a 5.5 per cent fuel savings and still left room for further improvement. The careful analysis of operating conditions shows that the openings in the "smoke eliminator" were 23.2 sq in. as compared to a grate area of 52 sq ft (or 0.32 per cent of the grate area).

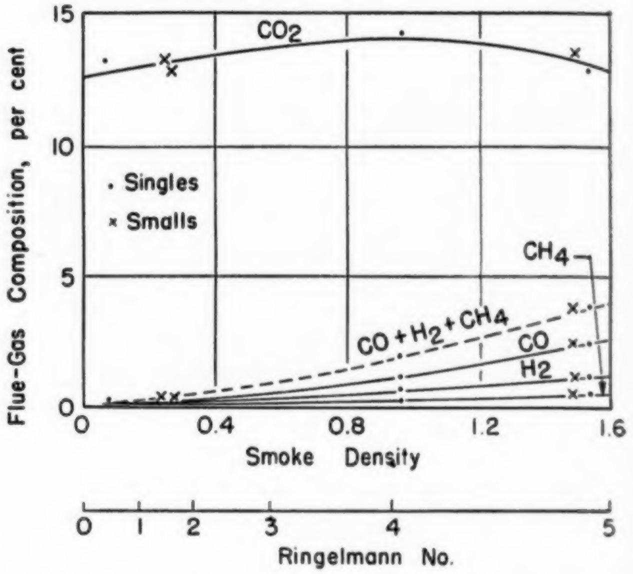

Fig. 5—Relation of smoke density to flue-gas composition (ref. 14)

Far better results have been achieved in a stationary boiler of the Fuel Research Station using 31.5-sq in. openings with a 51-sq ft grate or 0.43 per cent of the grate area, corresponding to 35 per cent larger openings. With a plenum-chamber pressure of only 0.7 in. water gage and 23.2-sq in. total nozzle area, the amount of overfire air is calculated as being 10.8 per cent of the total air, which must be considered as an inadequate amount under the prevailing condition of low pressure. A more desirable figure would be 15 per cent in agreement with FRS results, unless higher pressures are used as supplied by an independent blower.

Another series of experiments was conducted by the Fuel Research Station (15, 26) on a hand-fired, natural-draft, Lancashire boiler with and without a "smoke eliminator" installed in the fire door. The relation of smoke density* and the combustible gases which invariably accompany smoke production (14), is shown in Fig. 5. The combustible gases represent a multiple of the heat loss, by the carbon itself amounting up to 10 per cent at 1.6 smoke density (Ringelmann No. 2). The overall effect of the smoke eliminator, including the use of some additional air (excess air increased from 1.2 to 1.34) was an increase of boiler efficiency from 66.2 to 72 per cent, representing a fuel saving of 8.75 per cent. Smoke density has been reduced from 1.2 to 0.07, the latter figure representing practically invisible flue gas.

Locomotive Furnace

The hand-fired locomotive firebox has been an old-time smoke offender because of its high fuel rates and its limited combustion space. Marine installations offer a similar problem, especially those smaller furnaces used in inland navigation where the proper mixing of air and gas is often neglected. The necessity for proper mixing of air and gas has been recognized since the early history of railroading, and a number of devices aiming to bring about smokeless combustion have been invented and

* Smoke density is defined as log I_0/I_t; I_0 is intensity of the light beam entering the smoke; I_t is intensity of the beam emerging from the smoke; thickness of the smoke column is 1 foot.

have been in use for more than 50 years. Overfire air jets, suggested by an Austrian railway engineer named Langer, were improved and simplified by Marcotty. The latter's device uses mechanically controlled air slots in the firedoor, which open as the door is opened for fueling and remain open. When the door is shut after a certain time, these slots close again, and then steam jets or a "steam veil" are introduced as a mixing agent to mingle the gas and the overfire air, and also to push the flames back and lengthen their path. The Marcotty jets and the Marcotty perforated stay-bolts for introducing steam through the double-walled firebox have been standard equipment in a number of Continental locomotives (16). De Grahl (7) reports some results with and without the Marcotty device on a locomotive.

TABLE 1. DESIGN DATA OF THE BOILER

From A. R. Mayer[38, 39, 40]

Condition	
Steam, lb per hr	15,430
Pressure, psig	569
Temp, F	644
Boiler heating surface, sq ft	1,615
Grate area, sq ft	72.4
Free grate area, per cent	10
Combustion chamber, vol., cu ft	1,059
Width of grate, ft	4.92
Depth of furnace (not incl. front arch) ft	11.8
Height of combustion chamber, above grate, ft	16.4
Overfire-air nozzles, number	5
Size of nozzle, mm	20 x 40
	10 x 50
	20 x 50
	30 x 70
or 0.775 to 3.255 sq in. (each)	
Height above grate, ft	5.58
Slope, deg (down)	35
Location of nozzles	Front wall above front arch
Spacing, in.	13.8

Farmakowsky (10) tried a special type of nozzle for steam-air jets, after the nozzles suggested by Erdelji failed in duty by burning off rapidly. The special nozzles have air-cooling and are automatically switched to steam-cooling if the air is shut off as the firedoor is opened.

Traveling Grate Stoker

In Europe, most of the investigations on overfire air have been conducted on traveling grate stokers, because of the wide application of this type. Any type of mechanical stoker offers a better chance, than does a hand-fired furnace, for eliminating smoke and combustible gases, although, since a large part of the combustion takes place in the combustion chamber above the fuel bed, there will still be a small percentage of unburned gases, perhaps showing up only in the "unaccounted-for" loss of the heat balance. Since there are fluctuations in time and space, an exact determination of these small amounts of combustible gases is no easy task, so this heat loss sometimes not only escapes detection, but is even forgotten to be calculated by the operator. However, since 1 per cent CO represents roughly a heat loss of 4 to 7.5 per cent in the usual range of 15 to 8 per cent CO_2 content of the flue gases (21), it will certainly pay to eliminate even the slightest traces of unburned gases.

An even more important factor is the bringing about of complete combustion through increased turbulence above the fuel bed. The turbulence serves to equalize the prevailing zones of air deficiency at the front end and of air excess at the rear end, thus cutting the requirement of furnace space and making higher fuel rates practicable without impairing the combustion efficiency. Meier's investigations (20, 41) would indicate that overfire air is more effective in equalizing gas composition than an arrangement having a large number of stoker compartments.

Since the air jets are primarily a means to promote the turbulent mixing rather than to supply additional air, there is no direct correlation of volatile matter and secondary air quantity; but instead, there is direct relation between jet velocity and volatile matter of the coal. Even small quantities of air injected with sufficient pressure have had excellent results. Schultes (58) reported on the operation, in a sugar factory, of a plant having a maximum capacity of 33,000 lb per hr with 105 sq ft of traveling grate, under widely varying loads, where 5 per cent overfire air was injected at a pressure of 13.8 in. water gage. The five nozzles had a total area of 10.5 sq in., were arranged in the front arch and directed toward the fuel bed. With no overfire air, the stack showed a light-gray-to-black smoke cloud which disappeared completely within 30 seconds after turning on the overfire air.

Overfire air jets, usually arranged in or above the front arch are now considered part of the standard accessories of traveling grate stokers (1, 45), regardless of the type of fuel used.

TABLE 2. FUEL ANALYSIS AND OPERATING DATA

From A. R. Mayer[38,39,40]

Fuel Analysis	
Low-volatile bituminous coal (Lower heating value, H_1 = 13,874 - 14,531 Btu per lb)	
Components	Per Cent
H_2O	1.2 - 7.4
Ash	2.8 - 6.9
Volatile matter	15.3 - 20.4
High-volatile bituminous coal (H_1 = 12,796 Btu per lb)	
Components	Per Cent
H_2O	4.2
Ash	4.5
Volatile matter	36.6
Operating Data	
Steam rate, lb per hr	11,023
Fuel rate, lb/(sq ft) (hr)	15.4 - 18.7
Height of fuel bed, in.	3.94
Grate speed, fpm	0.187
Excess air ratio (avg)	1.6 - 1.7
Secondary air, per cent	4 - 25
Secondary-air pressure, in. water gage	0.787 - 15.98
Velocity, fps	58 - 1332

A very clear picture of the effect of overfire air and of the necessity of controlling certain conditions of jet operation such as pressure, velocity, sizing of the nozzles, etc., is traced by the experimental work of A. R. Mayer (38–40). The boiler used was small, but of rather modern design, with widely spaced water-wall tubes and a compartmented traveling grate stoker. Some of the design data are summarized in Table 1 and operating

data in Table 2. Most of the tests were run with a low-volatile bituminous coal having an average analysis as given in Table 2. Each test included not only a full boiler test but also a simultaneous gas sampling at 45 points within the combustion chamber at different levels and depths. An evaluation in terms of "degree of combustion" (as suggested and successfully used by Rummel and Schwiedessen (52) was not applicable in the case of a solid fuel. As a substitute presentation, inventory of heating value, as calculated from the complete gas analyses, was selected for the demonstration of the experimental results.

Without overfire air, as seen in Fig. 6, strata of combustible gases are sent into the combustion chamber, and they still have not completely vanished by the time the gases reach the boiler tube bank, as indicated by the zero-heating-value curve which is not closed. Apart from heat losses, soot formation and soot deposits, the delayed combustion may result in irregular steam temperatures. Fig. 7 shows that with overfire air injected at a plenum-chamber pressure of 7 in. water gage, the combustion as a whole is much improved; the combustible gas is pushed more to the rear end where a higher excess of air is prevailing; the zero-heating-value line although not yet completely closed, is nearing its ends, and a smaller percentage of combustible gases will escape with the flue gases entering the tube banks. Fig. 8 shows that a further increase in pressure to 10 in. water gage definitely affords complete combustion, and requires no more than about half of the available space, so the furnace could be smaller or the fuel rate considerably increased without disadvantage. It may be mentioned that, from reasons other than the overfire-air-jet installation, fuel rates were rather low, and most of the tests were run at a boiler capacity of 11,000 lb per hr, as against the 15,400-lb per hr design capacity. These tests and Figs. 6 through 8 (selected from a number of other presentations of gas composition and heating values across the length and width of the furnace in the original papers) demonstrate how overfire air works, and what the conditions of effective operation are. These test results with a small boiler at a moderate rate, may not be generalized or taken as absolute prescription data, yet they do afford a good insight into the mixing performance in the combustion chamber and on the bearing of pressure and velocity; they also confirm the suggestions given by Fig. 2.

From these experiments, Koessler (31) concludes that apart from design details on nozzle arrangement, optimum height above the fuel bed, and slope (which factors were not varied in Mayer's experiments), the effectiveness of overfire jets is a proved fact, and that the importance of plenum-chamber pressure and initial velocity should be fully realized. The possibility of decreasing volume and height of the combustion chamber is definitely established, thus making overfire air an attractive feature even in cases where the problem of unburned gases or smoke emission is not too objectionable.

No Overfire Air — Overfire-Air Pressure, 7 inches water gage — Overfire-Air Pressure, 10 inches water gage

Figs. 6, 7 and 8—Lines of equal heating value (kg-cal per std. cu m) of flue gas, firing low-volatile bituminous coal at a fuel rate of 28 lb per sq ft per hr (ref. 39)

Other Types of Mechanical Stokers

Little information is available about types of stokers other than hand-fired or mechanical plain grates and traveling or chain-grate stokers which are widely used. Multiple-retort underfeed stokers are used only in small numbers in Europe and no experimental work is reported on them. These underfeed stokers differ widely from the others in the matter of gas distribution and gas composition, in gas and smoke emission, and in the pattern of devolatilization; yet, most of the conclusions drawn from experimental work on traveling grates hold also for any other type of stoker. None of the stokers is absolutely free from the possibility of having a constant or a temporary heat loss from combustible gases, from having smoke formation and emission at all rates, and none of them can dispense entirely with turbulent mixing in the combustion chamber and still claim combustion equal in effectiveness with overfire jets (26). Sherman's investigations (61), although carried out for a different purpose, show the evident need for a more intense mixing, which is as necessary as it is in other types of stokers.

Effect on Slagging

The increase in efficiency which, it is true, may be small in large mechanical stoker furnaces is only one of the advantages of overfire air jets. Another advantage

is in the possible increase of fuel rates, provided that the fan is able to function with this increase. A third advantage, and a very important one, is that overfire air minimizes slagging.

Higher temperatures caused by the combustion in reduced space produce a number of effects not only on the combustion process itself but also on secondary reactions, and on heat transmission throughout the boiler system. The effect of the intense flame close to the fuel-bed, on ignition by radiation, has already been mentioned, a factor having considerable bearing if low-grade, moist, or low-volatile, slow-igniting fuel is used. The possible effect on a higher initial furnace temperature, and, consequently, on heat transfer has been emphasized by Koessler (31). The use of complete combustion as a means of minimizing furnace slagging and boiler and superheater deposits and, in reverse, lower temperatures as a source of this type of operation trouble, has been stressed by Zinzen (68), and others (22). This effect refers mainly to the necessity of complete oxidation not only of combustible matter (in the usual sense) but also of silicon-, iron-, calcium-sulfide and other sulfides.

As an example, Cleve (4) mentions a 1280-psig, 110,000-lb per hr boiler with traveling grate, firing low-volatile bituminous coal in sizes 0 to $^3/_8$ in. Heat liberation amounted to 18,000 Btu per cu ft of furnace volume, but slagging was excessive, so that the boiler could be operated only 700 hr between cleanings. By adding overfire air jets in the front and rear wall, and by injecting 10 per cent of the total air at a pressure of 12 in. water gage in the front wall, 5 per cent at 10 in. water gage in the rear wall, slagging disappeared completely, the operating cycle increased to over 3000 hr, and boiler outage was no longer caused primarily by slag deposits.

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Facts and Figures

One cubic foot of solid coal weighs slightly more than 81 lb.

•

The U. S. Bureau of Mines estimates the bituminous coal reserves in the United States to be approximately 3180 billion tons.

•

The energy contained in a pound of fissionable uranium is estimated as equivalent to that of about 1300 tons of good quality coal.

•

There are several postwar power stations in this country now operating with net heat rates of considerably less than 10,000 Btu per kwhr.

•

It is reported that a helicopter was recently employed in rigging staging hooks, pulleys and ropes for painting the 150-ft stack of a factory.

•

The density of saturated steam increases more than seven-fold from 500 psi to 2500 psi, whereas over the same range the water in a boiler weighs only about two-thirds as much.

•

According to Benjamin Fairless, president of U. S. Steel, it will require more than $90,000 to provide the tools and facilities that each worker will require in a new steel plant now under construction for his company.

•

The American bituminous coal miner averages a production of 6.48 tons of coal per man-day in contrast with 1.99 tons for Poland, 1.64 tons for Britain, and 1.42 tons for the Ruhr. The high degree of mechanization of coal mines in the United States is a dominant factor in the high output.

•

The Atomic Energy Commission announces that a means for reducing radioactivity in contaminated liquids has been developed at the Oak Ridge National Laboratory. This involves passing the contaminated liquid through a series of filters containing steel wool, clay, activated carbon, an anion-exchange and a cation-exchange resin.

Steam Sampling and Testing

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Inconsistencies and the possibilities of error in results obtained by generally accepted methods of sampling and testing are discussed; and, by means of examples, the value of taking special samples for definite purposes is illustrated. Furthermore, the need is stressed for critical analysis of the results before reaching conclusions.

In considering the design and merits of a system for sampling and testing steam, the purpose for which the results are to be used may be the most important factor involved.

The purity of steam from a power boiler may be determined for one or more of the following reasons:

1. Checking the boiler manufacturer's guarantee.
2. Operational control and record.
3. Investigation of a suspected or known carryover condition.

In the first case, it is of major importance that every precaution be taken to obtain a sample that is representative of the total steam flow, and to determine its purity by methods that insure maximum accuracy and a minimum of error due to contamination and dissolved gases.

For operational control and record, the important factor is continuity of the record and ability of the record to indicate development of potential or actual carryover conditions in the boiler. For this purpose, it may be more desirable to sample the steam at locations where potential carryover is most likely to first register, rather than to sample the average output. Depending on local conditions, extreme care in elimination of dissolved gases and minor contamination may not be necessary, as changes in the purity values are of more significance than the actual values themselves.

The object in investigation of a suspected or known carryover is partly to establish the fact of carryover, its amount, and the conditions pertaining to it, but chiefly to locate and identify the source of the carryover so that proper corrective steps may be taken. In such work, orthodox methods of sampling and testing may be of less value than special samples taken within the drum, across the boiler, or at other selected locations.

A large amount of work has been done and publicized on methods of sampling and testing steam. The design of standard sampling nozzles, the decline of steam calorimetry and the development of conductivity methods, the problems of degasification, gravimetric methods of determining steam purity, silica vaporization and special methods for investigation of carryover have all received attention.

In spite of the study given to these problems, there are inconsistencies in results which are difficult to explain on the basis that results obtained by current methods of sampling and testing are entirely reliable. Rationalizing results, obtained by accepted methods, is seldom acceptable to all parties involved, but in many cases interpretation is necessary for correct conclusions.

Numerous modern boilers deliver steam having a measured steam impurity of from 0.2 to 1.0 ppm and these determined values are seldom seriously questioned. It may be assumed that the source of the impurity is boiler water, probably in the form of fog or mist, that is not completely removed by the steam purification equipment. The impurities in the boiler water are, of course, the actual source of the solids impurity in the steam, but such impurity is carried out of the boiler in conjunction with liquid water. With the exception of silica carryover, this is the generally accepted mechanism of carryover.

It logically follows, therefore, that the amount of fog or mist might be expected to vary with changes in rating and steam velocity, and that the quantity of solids associated with the fog or mist would vary with changes in boiler-water concentration. Thus a carryover of 0.1 per cent moisture from a boiler operating with boiler-water concentration of 2000 ppm should logically result in steam having 2 ppm impurity. If the steam output from the boiler is increased, the 0.1 per cent moisture might be expected to increase to give higher impurity in the steam. If the boiler-water concentration, at constant rating, is reduced to 500 ppm, the impurity in the steam should decrease to about one fourth of the impurity at 2000 ppm concentration.

Tests of steam purity, not only from similar boilers, but from any single boiler, operating over a wide range of

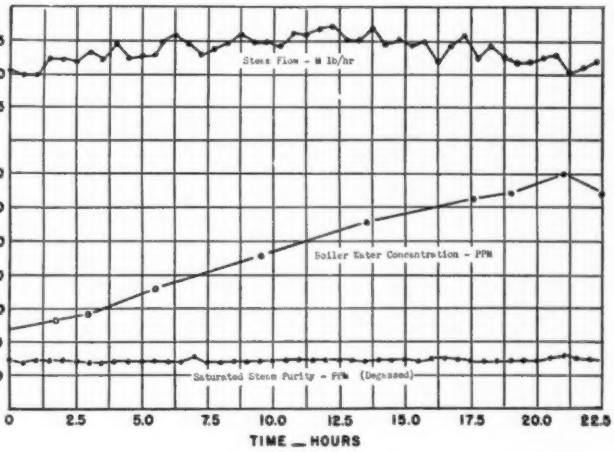


Fig. 1—Showing negative effect of boiler water concentration changes on measured steam purity

rating and boiler water concentration, do not normally show such relation between impurity, rating and concentration. Within reasonable limits, the measured steam impurity remains practically constant regardless of changes in rating and concentration. In cases where these expected variations do occur, it is usually found that leakage in the drum internals is involved. For example, in one case, steam output was varied from 150,000 to over 350,000 lb per hr, and boiler water concentration was varied from less than 100 to over 2000 ppm without appreciable change in measured steam purity. In another case, the measured impurity in the steam from a central station boiler was about 0.6 ppm by careful gravimetric determination, yet the boiler water concentration was less than 100 ppm. The equivalent moisture carryover of over a half per cent from such a unit is unbelievably high.

In Fig. 1, a typical example of this paradox is shown. At more or less constant rating, boiler water concentration was increased more than tenfold, from 200 to 2500 ppm, without change in the measured impurity of the steam. The degassed steam registered $1^1/_2$ ppm impurity, but this value is obviously much too high. If a carryover of $1^1/_2$ ppm results with boiler water of 200 ppm, then with 2500 ppm boiler water the impurity in the steam should logically be over 15 ppm. In this case, it may be conceded that the measured high impurity was probably due to unremoved gases in the steam. The same paradox holds, however, for purity values sufficiently below 1 ppm to be seldom questioned.

Negative effect of changes in rating on steam purity may be explained on the basis that steam dryers act as filters and remove practically all moisture from the steam over their effective range of velocity, regardless of the normal variation in moisture entering the dryer. Negative effect of changes in boiler-water concentration on steam purity is difficult to explain unless it be assumed that the actual impurity in the steam is so much smaller than the measured impurity that these normal and expected variations are completely masked by more or less constant errors due to unremoved gases and sampling line contaminations.

Where no carryover problems exist, it is perhaps of little moment whether the steam measures 0.1 or 1.0 ppm impurity, except where it is desired to equal the records of other plants, or where the boiler manufacturer has to demonstrate a guaranteed steam purity. A very pertinent question of practical value, however, is how clean steam must be in order to avoid turbine and superheater deposits, and whether current methods of sampling and testing are accurate enough to furnish a satisfactory answer to this question. It would be desirable to establish trouble-free standards of steam purity, but it seems likely that sampling and test methods will have to be improved before such standards can be determined.

As far as superheater deposits are concerned, experience suggests that some minimum limit of impurity is sufficient to avoid tube failures and washing. It is suggested that superheater deposits develop only when there is sufficient moisture carryover or condensation to form a film of water on the inside of the tube at the superheater inlet. Evaporation of this film at the tube surface results in salt deposition in the inlet section of the element where superheating begins. Below some minimum moisture content, no surface film is formed and the moisture is evaporated in space, the resulting solids being blown through the superheater without deposition.

On this premise, a variety of operating conditions may or may not cause sufficient deposit to be troublesome. A low-concentration boiler water may not give sufficient deposit to insulate the tube even though the moisture carryover is sufficient to form a film. Even small amounts of moisture carryover of a high-concentration boiler water may be sufficient to give troublesome deposits. The operating period between shutdowns, and variations in rating, are also involved as deposits are washed off by condensation during shutdown periods and are spread over a greater area by a variable load condition.

As concerns turbine deposits, variation in records complicated by silica carryover allow no definite conclusions. If current steam impurity determinations are to be accepted, the total amount of solids that pass through a turbine over a period of time is certainly far greater than the amount of solids found on the turbine blades.

Average and representative steam samples, such as obtained for checking guarantees, and as generally used

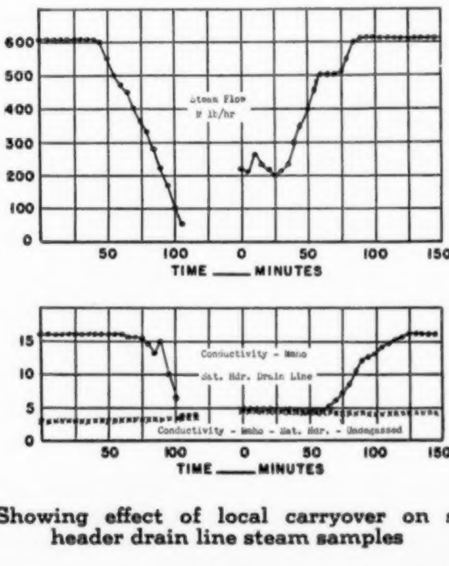


Fig. 2—Showing effect of local carryover on saturated header drain line steam samples

for operating control and record, may not show the presence of small local carryover, and the carryover may not be suspected until after failure of superheater tubes or the accumulation of deposits on turbine blades. Such local carryover is often enough to cause repeated failure of certain superheater elements but not sufficient to affect appreciably the measured purity of the average steam sample. Special sampling methods are usually necessary to locate and identify this form of carryover.

One method of special sampling that has been used to detect local carryover is to traverse the width of the boiler by sampling from each steam circulator between the drum and superheater header. Using a standard perforated tube nozzle in the circulators will, in most cases, indicate the point of local carryover, but in some cases even this traverse method will not reveal the source of the carryover.

In Fig. 2, an interesting case of special sampling for the purpose of tracing a known carryover is illustrated. Loss of superheater tubes at one side of the boiler suggested carryover, yet the degassed steam purity tests had never indicated carryover in excess of about a half part per million, and continuous records showed no periodic carryover due to changes in operating conditions.

On the basis that a local carryover at the side of the boiler might give a concentrated sample at the drain line of the saturated header, due to partial separation in the header, a sample from the drain line was checked and found to test some 16 mmho. Dropping the rating reduced this conductivity to that of the regular average steam sample, and increasing the rating restored the conductivity to its previous value. It will be noted that the change in conductivity developed when the rating was about half to three quarters of full load, characteristic of leakage carryover. A similar check of steam from the drain line at the other end of the header gave sample conductivity equal to that of the regular sample.

These characteristics, and the difference between conductivity of the drain line samples at each end of the header, indicated that the cause of the superheater failure was a local carryover which was likely due to leakage in the drum internals. The unit was taken off the line and the leakage was found and sealed up. Subsequent tests of drain line steam gave conductivity the same as that of the regular sample.

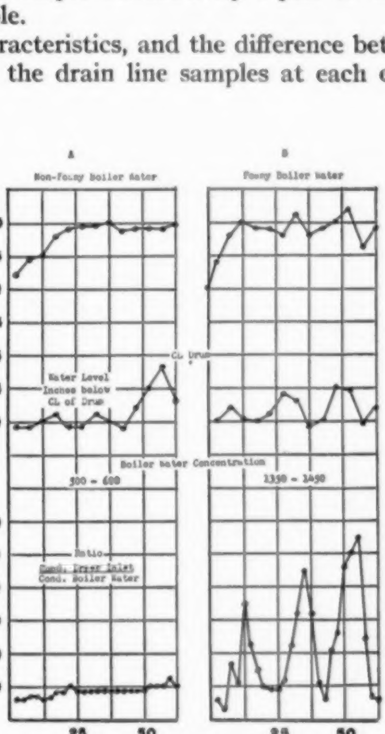


Fig. 3—Showing use of dryer inlet sampling for indicating development of foaming

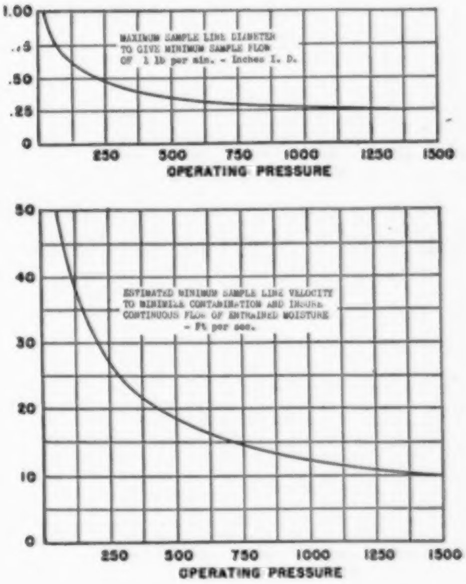


Fig. 4—Estimated sampling line velocities

This illustrates the value of special sampling methods, which in this case permitted diagnosis of the problem quickly and without shutting down the boiler. In many cases, the cause of the failures would not be attributed to carryover in view of the purity record of the regular steam sample, and correction delayed by making noncorrective changes. Degasification of the steam was not necessary to check this carryover problem. The differences in conductivity and the change in conductivity with rating are the significant values rather than the absolute degassed steam purity. It will also be noted that reduction in rating from 600,000 to 50,000 lb per hr made no change in undegassed steam conductivity of the regular sample, an indication that a large proportion of the measured undegassed steam conductivity must be due to gases rather than carryover.

The leakage in this case was very small, but locally it was sufficient to cause local superheater failure. It was not enough to affect appreciably the conductivity of the regular sample, which was practically the same after the leakage was corrected.

The plant at which these results were obtained now places much value on header drain samples as a measure of their steam purity. This confidence, however, must be tempered by the possibility that local leakages near the center of the boiler might not register on drain line samples at the ends of the header, and the fact that such methods of sampling are unorthodox. The case, however, illustrates the value of a special sampling method for a particular purpose.

Another type of special sampling is shown in Fig. 3. In this case, a sample line is installed within the boiler drum at the inlet of the steam dryer. When making steam purity tests where foamy boiler water concentrations are involved, anticipation of foamover is desirable

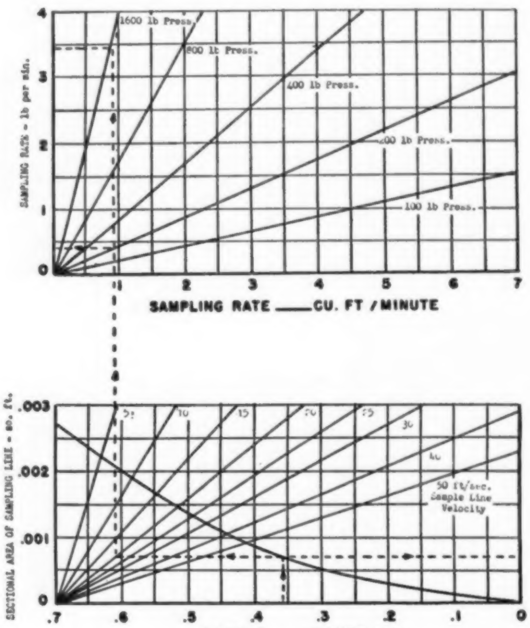


Fig. 5—Relation between sampling rates, sample line velocities, and line sizes

to avoid excessive carryover to the superheater during the test. The dryer inlet sample will register development of foaming in the drum before carryover from the drum develops, and often this warning will allow time to blow down or otherwise control the foaming condition before actual carryover occurs.

The development of foam at the dryer inlet is identified by the radical change in the ratio of the conductivity of the dryer inlet steam over the conductivity of the boiler water. This ratio roughly indicates the percentage of moisture in the mixture and foam-steam mixtures contain much higher amounts of boiler water than spray-steam mixtures.

In the left half of Fig. 3 are shown results with a nonfoaming boiler water where the mixture to the dryer is a spray-steam mixture. The conductivity ratio is relatively low and is well within the capacity limits of the dryer. In the right half of the chart, at higher boiler-water concentrations, the ratios show peaks of 35, 45 and 55 per cent moisture steam due to shots of foam created by variations in water level. Thus, this special sample gave warning of potential carryover and allowed determination of concentration limitations without any carryover to the superheater during the test. A continuous conductivity record of dryer inlet steam has been used as a guide to operators for control of blowdown and prevention of periodic foamover.

In general, a rapid or sudden change in the ratio from less than 10–15 to over 20–30 is a fairly reliable indication of change from a spray-steam mixture to a foam-steam mixture. Continued operation with a high ratio is likely to flood the dryer and result in heavy carryover to the superheater.

For sampling steam for purity determinations, not only is the design of the sampling nozzle important, but the design and arrangement of the rest of the sampling system must be considered if reliable and accurate results are to be obtained. To minimize contamination of the sample, it should not be in contact with the sampling system any longer than absolutely necessary. Liquid films, which form on the inside surface of the line, pick up contamination unless they are kept moving at steam flow velocity, and moisture in the sample tends to accumulate in pockets in the system unless steam velocity is sufficient to keep such pockets clear. These effects may be obtained in uninsulated sampling lines where continuous condensation continuously reduces line velocity, and at the same time increases the amount of liquid to be carried through the system. The effects are not serious in short, small-diameter lines which can drain continuously in the direction of flow, but they may be very noticeable in long, large-diameter lines that have horizontal stretches and pockets followed by vertical flow.

As operating pressure increases, the density and carrying capacity of steam increases, and at high pressure sampling-line velocity can be appreciably lower than at low pressure. Fig. 4 gives estimated minimum sample line velocity at various pressures, to minimize contamination and insure continuous flow of entrained moisture, and the maximum diameter of sample line to give a sample flow of 1 lb per min at the desired velocity. In the absence of any reliable data on sample line velocity, these values are tentative estimates but they illustrate a neglected phase of steam sampling and suggest that usual sampling rates may often be too low to give reliable results.

In Fig. 5 is shown the variation in sample line velocity for various rates of sampling at different pressures and for different diameters of sampling lines. To maintain a velocity of 20 ft per sec in a $^1/_4$-in. pipe line requires less than a half pound-per-minute flow rate at 200 psi pressure, but nearly a $3^1/_2$ pound-per-minute flow rate at 1600 psi pressure.

Data on contamination in sampling systems and the effects of sample line velocity are very limited. In one case a conductivity of one mmho, obtained by sampling

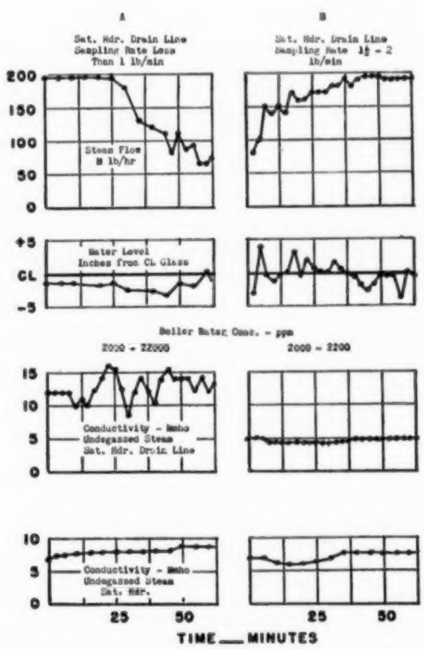


Fig. 6—Showing effect of sampling rate on test results

at the top of the boiler, was doubled when the line was extended down to the operating level. Sampling rate in this case was limited by cooling water capacity. In another case, only 0.2 mmho difference in conductivity was noted for short and long sample lines where the flow rate was liberal. A minimum of contamination was evident in a third case where the sampling rate was very liberal and the sample was piped to the basement of the plant through standard iron pipe. The undegassed steam conductivity was less than 0.25 mmho.

Regardless of the system of sampling or method of testing employed, constant vigilance and a critical attitude are necessary to insure reliable data and correct conclusions. Too often results obtained by approved methods are accepted without question, and misleading interpretations and conclusions are drawn without critical analysis. For example, the conclusion normally drawn from the results shown in Fig. 1 would be that the steam contained $1^1/_2$ ppm impurity and was not as good as it should be. In the absence of drain line sample results in the case discussed for Fig. 2, the normal conclusion might be that the superheater failure could not be due to carryover because the steam tested less than $^1/_2$ ppm impurity.

Fig. 6 represents a case of faulty test results that were salvaged when inconsistencies would not stand up under critical analysis and errors were indicated. In this case, a temporary drain line sample connection was installed to check for a suspected local leakage carryover. Regular steam samples could not be conveniently degassed, but spot checks indicated that practically all of the measured conductivity was due to gases in the steam. The temporary connection for the drain line sample was a relatively long line of $^1/_4$-in. pipe and there were pockets in the line. Since carryover was suspected, the initial erratic drain line conductivities shown in the left half of Fig. 6 appeared to confirm the suspected leakage condition. During the test, however, it was noted that the variations in the conductivity appeared in cycles which could not be correlated with changes in operating conditions. Suspecting that the cycles were due to periodic clearing of pockets in the line, and that the sampling rate was too low, the sampling capacity was increased and the drain line sample immediately registered indication of no local carryover as shown in the right half of Fig. 6. Correcting this sampling error eliminated the necessity of shutting down the boiler for inspection and making possible changes in the drum internals.

The examples here discussed have been selected because they clearly indicate the particular feature of sampling and testing under discussion. They illustrate the value of special samples when taken for a definite purpose, the possibilities of error in generally accepted methods of sampling and testing, and the need for logical and critical analysis of the results before making conclusions.

It is likely that in the average case, the impurity in commercial steam is much less than indicated by current test methods. The conductivity method is the best and most accurate method available, but sampling systems and degasification methods impose limitations on ability to measure the actual and absolute purity of the steam. These limitations are not a serious handicap if they are recognized, and misleading conclusions are not drawn.

A.S.M.E. Spring Meeting Features Varied Program

AT THE 1951 Spring Meeting of the American Society of Mechanical Engineers held at the Atlanta Biltmore Hotel, Atlanta, Ga., April 2–5, there were 21 technical sessions and more than 45 papers sponsored by committees and professional divisions of the society. Engineering manpower developments which may effect every member of the profession were the subject of an address by **J. Calvin Brown,** president of ASME, on the opening day of the meeting.

In keeping with the geographical location of the meeting a number of the speakers told of accomplishments in the South and discussed problems of special concern in that area. **Frank F. Groseclose,** director of the School of Industrial Engineering, Georgia Institute of Technology, spoke on "The Importance of Southern Industry to the National Economy." Another regional paper was by **Prof. Howard P. Emerson** of the University of Tennessee, whose topic was "Status of Scientific Management in the Southeast."

Of particular interest to COMBUSTION readers were papers delivered at sessions dealing with dual-fuel firing, cooling towers, utilization of waste materials, mercury steam plants, and the heat pump. Abstracts of many of these papers follow.

Utilization of Waste Materials

There were two papers on this general topic. The first was by **W. H. Kuhn** of The Fairfield Engineering Co., **E. A. Carsey** of The Kirk & Blum Manufacturing Co., and **D. L. Gusler** of Bassett Furniture Industries, Inc., whose subject was "Power from Wood Waste." Limiting their discussion to the collection, storage and combustion of kiln-dried sawdust, chips and shavings in a modern furniture factory, the authors pointed out that the energy recovery may amount to between 8000 and 8500 Btu per pound of wood waste. In a plant processing 40,000 board feet in 24 hr, the amount of combustible scrap is estimated as 26,000 board feet or a total of 78,000 lb.

The paper described one of three identical installations at plants of the Bassett Furniture Industries, Inc. The collecting systems are designed to produce 200,000 cfm of air to handle shavings and sawdust. Hogged refuse is handled by separate, extra-heavy fans with somewhat higher pipe velocity than the regular system. A horizontal bin with a live bottom is used for the storage of wood waste and subsequent feeding to the boilers. The wood waste is kept at uniform density throughout the bin by constant agitation, eliminating arching because there is no opportunity for shavings and sawdust to pack. This system is developed around three sets of drag-type conveyors, two operating at constant speed in one direction and the third at variable speed in the opposite direction. These conveyors function in conjunction with a recirculating type of blower system and maintain agitation.

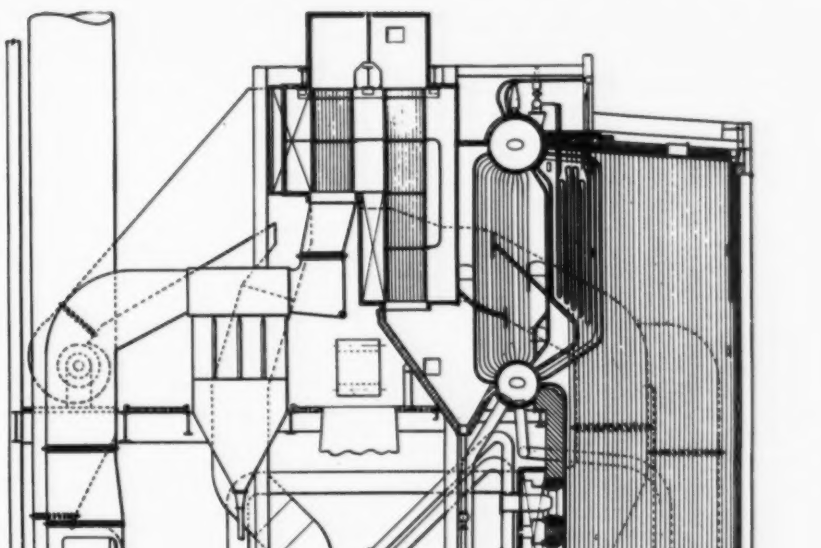
Each plant has two boilers rated at 20,000 lb of steam per hour and operating at 200 psig. Wood waste, which is the primary fuel, is fed to each boiler through a set of three screw feeders. Coal is burned as a stand-by fuel on pneumatic-type spreader stokers. The combustion-control system is designed so that coal is fired whenever the supply of wood waste is insufficient to sustain load requirements. The screw-feeder discharge chutes terminate immediately above high-velocity, low-volume air jets which establish turbulence and partial distribution.

The authors reported that the new installations were able to produce 6.7 lb of steam for every pound of wood waste.

The second paper on utilization of waste materials was presented by **A. S. Weigel** of Combustion Engineering–Superheater, Inc., whose subject was "Developments in Spreader Firing of Wet Wood." In the manufacture of lumber, pulp and paper and naval stores there are large quantities of hogged wood and bark, "spent" chips and other wood wastes which fall within the size range and moisture content suitable for spreader-stoker firing. Impetus for recent developments of this type of firing has come from the increasing value of wet wood and the demand that it be burned more efficiently. The spreader stoker meets this demand and also has the following advantages: low maintenance and operating costs, ability to control the fuel-air ratio accurately, rapid response to load demands, high heat release rates and practically continuous boiler availability.

For best operation the wet fuel should be sized so that approximately 95 per cent will pass through a 2-in. square mesh screen. An occasional oversize piece up to 12 in. long and 1 in. thick that will pass a 4-in. bar screen may be permitted, but an excess of such pieces will cause materials-handling problems and blanketing of the fuel bed. Maximum moisture content should not exceed 60 per cent as fired.

A thin active fire produces best results, the optimum fuel depth being about $2^1/_2$ in. This amount is required to keep the



Steam generating unit designed to burn wet wood and pulverized coal

grates completely covered. Air for combustion is supplied at relatively low pressure under the grates, and jets of either air or steam at higher pressure are directed through the furnace walls over the fire to create furnace turbulence. Except for a small amount of leakage, all air to the furnace is under control. Since the quantity of fuel fed can be measured, the fuel-air ratio can be closely regulated and excess air held to the desired quantity. This has the effect of reducing periodic high furnace velocities and results in a lower carryover of char. With automatic regulation the desired fuel-air ratio may be maintained over a load range of approximately 3 to 1.

Mr. Weigel cited several typical installations where spreader stokers have been applied for burning wet wood. At a Northwestern lumber mill a dumping-grate spreader stoker was installed in an existing boiler which was previously equipped with a dutch-oven, cell-type furnace. Since this stoker was placed in service the boiler has carried an average load of over 75,000 lb of steam per hour for 24-hr periods, with extended peak loads of 90,000 lb per hr. A companion boiler of duplicate design still using cone firing has a maximum capacity of 65,000 to 70,000 lb per hr.

A combination of natural gas and hogged bark is burned in an installation in a Southern paper mill. The natural gas burners are located in the front wall, and the continuous-discharge spreader stoker is at a lower elevation. The unit is rated at 150,000 lb per hr on gas or a combination of gas and bark.

Another interesting installation combines the burning of wet wood and pulverized coal. The furnace has been arranged to prevent the coal ash from falling on and interfering with the stoker fuel bed. Maximum design capacity is 200,000 lb per hr on coal or a combination of wood and coal, but the unit has carried loads of over 200,000 lb per hr on wood only.

At a Southern naval-stores plant a continuous-discharge spreader stoker has been installed to burn spent wood chips having an average moisture content of 35 to 40 per cent. The distributor units are set high above the grate surface of a two-drum bent-tube boiler. A tubular air heater supplies air through a forced-draft fan to a series of overfire air nozzles in four tangential belts, providing a highly turbulent zone below the distributor units. The fine particles on entering the furnace burn in suspension, and the larger particles fall through the highly turbulent zone on their way to the grate. Operating results on this experimental unit have exceeded performance predictions.

Multi-Fuel Firing

A valuable paper on this subject was presented by **W. H. Decker** of the Sinclair Refining Co. under the title, "Multi-Fuel Burners: Their Application and Design." Fuel price and fuel availability are materially affected by one another, and the engineer designing a new steam plant is faced with the necessity of ensuring both minimum costs and continuity of operation at all times. If the designer can incorporate into the original installation all of the necessary equipment to handle solid, liquid or gaseous fuels, then the most economical overall operation will be assured. Under these conditions selection of fuel is determined by current market conditions. Though a multi-fuel installation has a higher first cost, a period of curtailed production or forced shutdown due to dependence on a single fuel may more than compensate for the additional cost.

"Availability" type combustion controls wherein fuels are proportioned to the burners in relation to their supply are now standard equipment in many plants. These controls can be operated so that any one fuel is fired in a fixed quantity, with the second fuel supplied to make up the balance of the load requirement as governed by the availability of a third fuel.

A correctly designed multi-fuel burner must be capable of burning efficiently any one fuel or combination of fuels at varying burner capacities. Since the combustion of a solid fuel is generally more difficult, a burner designed with sufficient turbulence and mixing for this fuel will usually be satisfactory for liquid or gaseous fuels. Such burners should be designed to furnish enough primary air to maintain both stable and rapid ignition, with the secondary air added under conditions of good mixing and turbulence beyond the zone of ignition.

Mercury Plant Operation

"Current Operating Results and Developments in Mercury-Steam Power Plants, 1949–1950" was the title of a paper by **Harold N. Hackett** of the General Electric Co. Three new mercury power plants having a total generating capacity of approximately 92,500 kw were placed in service in 1949 and the early part of 1950. Two of the mercury plants were topping units for existing steam turbines, while the third installation was a complete plant built on a new site for the purpose of generating electric power only.

The first of these units to go in service was the 15,000-kw topping unit installed in the South Meadow Station of the Hartford Electric Light Co. In addition to the electric power produced by the mercury turbine, this unit will produce 200,000 lb of steam per hr at 400 psig, 700 F when operated at the maximum design rating. Over a period of 15,312 hr, the total power produced by the mercury plant was 319,962,000 kwhr, of which 147,998,000 kwhr were generated by the mercury turbine-generator and the remainder by steam turbine-generators from the by-product steam. The average heat input was 10,150 Btu per net kwhr. The Hartford mercury unit is operated continuously at base load and at approximately maximum rating.

The second of the mercury units to go into service in 1949 was the 7500-kw installation at the Pittsfield Works of the General Electric Co. At rated turbine output this unit is designed to generate 113,000 lb of steam per hour at 640 psig, 825 F. Steam-turbine condensing facilities are limited at Pittsfield, and the mercury-steam unit provides an additional 7500 kw of efficient capacity without increasing the condensing load.

The third unit to be placed in operation was the 40,000-kw installation at the Schiller Station of the Public Service Company of New Hampshire. The power generating equipment consists of two 7500-kw mercury-turbine condenser-boiler sets, two radiant-type mercury boilers and one 25,000-kw steam turbine set. Throttle conditions are 105 psig, 934 F for the mercury turbines and 600 psig, 825 F for the steam turbines. The plant operates regularly on base load of 46,000 kw at a gross heat rate of about 9100 Btu per kwhr. When corrected for station auxiliary power, the heat rate approximates 9400 Btu per net kwhr, and it is expected that a heat rate of 9200 Btu per net kwhr will be achieved when the equipment is operated at design conditions.

The author listed several applications where the mercury-steam cycle may be used to advantage, including:

1. Complete condensing plants where only electrical power is produced. With plant capacities ranging from 12,500 to 130,000 kw, expected fuel input rates would vary from 10,500 Btu per net kwhr for the smaller units to 8800 Btu per net kwhr for the larger sizes.
2. Topping plants for existing steam stations where (*a*) an increase in electric generation is required along with additional high-pressure steam to existing turbines and where (*b*) additional electrical power and process steam are required for process or heating purposes.
3. Where there is (*a*) a deficiency of condensing water or (*b*) insufficient steam boiler capacity and a demand for additional electrical generating capacity.

Protecting Mercury Boilers from Attack

Richard C. Reid of General Electric Co. was the author of a paper entitled "Mercury Boiler Treatment with Titanium and Magnesium Metals" in which he discussed the action of those metals in protecting boiler steel from attack by mercury. Good heat transfer is also provided because the treatment maintains wetting of the boiler surface. The author made use of phase diagrams of the mercury-iron, mercury-titanium and iron-titanium systems in explaining the mechanism of the dissolving action of the metals.

When titanium is added to a mercury tube circuit it forms a precipitate, coating the boiler surface with a compound. As an excess of titanium is established in the mercury the iron surfaces are satisfied, and the excess of titanium is carried in the liquid vapor mixture as a finely divided wetted particle. To protect a boiler surface from attack by mercury, titanium metal must be added to the circulating mercury in a sufficient quantity to saturate the system. An excess of titanium must be maintained to satisfy requirements of metal surfaces and to replace any loss through the condensing system or removal by depositing.

Another problem in the operation of mercury boilers relates to the control of oxygen. Titanium metal acts as a deoxidizing agent, but due to its low solubility and the amount required it is not entirely satisfactory for this function in large mercury boiler installations. Magnesium

metal dissolved in the mercury of a boiler circuit is a satisfactory deoxidizing agent because of its ability to reduce titanium oxide and prevent its oxidation, thereby keeping this metal active in the boiler system. Magnesium will also reduce iron oxide, producing pure wetting iron and forming magnesium oxide. Magnesium oxide is precipitated from mercury solution as a minute non-wetted particle and carried in suspension until it settles out in a quiescent area or is removed from the boiler with the vapor.

Symposium on Cooling Towers

The first of seven papers making up the two-session symposium was presented by **A. R. LeBailly** of Sargent & Lundy whose topic was "Some Economic Factors in the Selection of Cooling Towers." One problem that confronts the engineer desiring to obtain a balanced design is to provide the same conservative margin in cooling towers as exists in other power plant equipment. The specified heat load of the cooling tower should be not less than the maximum flow to the condenser with the highest turbine capability, and in view of some recent experience it should also allow some margin above the capability limitation set forth in the turbine contract.

Cooling towers are subject to performance degradation due to age. Both chemical and biological deterioration may take place, and the designer should allow some degradation margin in cooling tower specifications. In locations where the peak load is coincidental with high wet-bulb temperature, design should be based on a closer approach to the maximum normal wet-bulb temperature than has been the practice heretofore. In making an economic study there should be an evaluation of extra turbine capacity available due to better vacuum. A comparison based on the yearly operating cost and fixed charges only without a consideration of the extra available capacity would be misleading and would not lead to the optimum selection.

Louis Elliott of Ebasco Services, Inc., was author of the second paper under the title, "Economic Comparison of Cooling-Tower with Direct-Condensing Plant." To make a hypothetical comparison he selected a 60,000/66,000-kw, 1250-psig, 950-F steam-electric plant and arrived at a computed fuel consumption from two to three per cent higher for the cooling tower than for a direct-condensing plant using river water. The spread may be accounted for by the combined effect of higher condensing-water temperatures and resulting higher back pressures for the cooling tower and because of the greater auxiliary use. For any given case, a careful estimate of relative temperatures and auxiliary uses should be made, and in some instances the results may be quite different from those obtained in a hypothetical study.

A cooling-tower plant may be considered as carrying slightly higher depreciation and maintenance expense than a direct-condensing plant. It is frequently found that a cooling-tower installation is economical when large expenditures for

storage reservoirs, intake structures ro long transmission lines are avoided.

"Selection, Operation and Maintenance of Industrial Cooling Equipment (Cooling Towers and Air-Cooled Exchangers)" was the title of the third paper which was by **Howard E. Degler** of The Marley Co., Inc. Modern cooling units, it was noted, require only about 1 sq ft of ground area as compared to 50 sq ft for the spray pond and about 1000 sq ft for a natural cooling lake or pond. Mechanical draft cooling towers can evaporatively cool water to a temperature approaching the wet-bulb temperature of the ambient air. This evaporative method requires less than one per cent evaporation of the water circulated to dispose economically of the heat load.

In the fourth paper entitled "Recirculation in Cooling Towers," **Joseph Lichtenstein** of Foster Wheeler Corp. observed that recirculation affects the ability of towers to furnish specified cold water temperature under specified operating conditions. Suitable design changes must be made to suppress recirculation, or if this is not possible it must be considered in the planning and dimensioning of required equipment. Each installation has a characteristic recirculation factor that can be selected from tests on similar types of installations. Specifications should include this recirculation factor, which can be used in determining the effect of recirculation on required equipment size and performance. The recirculation factor may be considered analogous to the cleanliness factor specified for condensers, and its specification will enable cooling-tower manufacturers to meet a need for a reliable cold water temperature guarantee.

"Operating Experiences with Cooling Towers in the Central Gulf Area" was the title of the fifth paper which was presented by **H. G. Hiebler** of the Houston Lighting & Power Co. Tower operation is dependent upon the reliability of fans and fan drives. Totally enclosed motors are recommended. Blade failures may wreck the fan and damage the gear. The most serious difficulties have been with worm-type reduction gears.

V. F. Estcourt of Pacific Gas and Electric Co. had as his topic, "Problems Relating to the Operation, Maintenance and Chemical Control of Cooling Towers for Steam-Electric Generating Stations." Cooling-tower performance must be considered not only in terms of heat dissipation but also in relation to the overall results obtainable with a particular combination of tower, condenser and turbine. There is an important relationship between turbine leaving losses and the optimum tower size. The higher average cooling water temperatures which usually exist with cooling towers tend to aggravate the problem of scale deposition on condenser tubes. This leads to a vicious cycle whereby the heat-transfer rate is decreased in the condenser with a resultant increase in condenser back pressure and heat load. This, in turn, raises

the cooling-water temperature, further aggravating the deposition of calcium carbonate scale on the condenser tubes.

Successful results are described in the use of threshold treatment of cooling-tower water with stabilized phosphate in combination with sulfur burning for keeping condensers free of scale deposits. This treatment is supplemented by chlorination to prevent algae growth in the tower.

The last paper in the symposium, "Deterioration of Wood and Cooling Towers" by **R. H. Baechler** and **C. Audrey Richards** of Forest Products Laboratory, was a report on investigations made in that laboratory to determine causes of wood failure. Redwood is used almost exclusively in cooling towers because of its inherent resistance to decay and its relative freedom from distortion with changes in moisture content.

Premature failures of redwood have been attributed to living organisms called fungi, which are responsible for decay, and to chemicals present in water. Physical erosion of the wood by water also plays a part in the reduction of cross section of members exposed to continuous flow.

Laboratory leaching studies were conducted in which the changes that might take place in cooling-tower wood were accelerated by the use of thin cross sections, high temperatures and relatively high chemical concentrations. In another series of tests pieces of slats removed from 12 towers after six to eight years' service, and exposed to five fungi in the laboratory, showed much greater loss in decay than pieces of unused redwood. Thin cross sections exposed to solutions of sodium carbonate and sodium hypochlorite were less resistant to decay than those exposed to water.

Heat Pump Application

James A. Eibling and **Bertrand A. Landry** of Battelle Memorial Institute reported on studies made for Bituminous Coal Research, Inc., on residential heating in a paper entitled "The Steam-Generating Station as a Source and Sink for the Heat Pump." The system described in the paper would require for its application the extended decentralization of power stations and a considerable decrease in the installed capacity in comparison with present large central stations.

It is generally agreed that the principal problem is to provide a suitable heat source, especially in northern localities where the maximum heating load is about twice the maximum cooling load. One possibility is to use the waste heat in the condensing cooling water from steam power stations as a source of heat for heat pumps in dwellings. During the cooling season, a centrally located spray pond would serve as the heat sink.

The proposed application involves the installation of an underground system of piping through which the water is circulated between the power plant and the heat pumps located in dwellings. One limitation is that there is a certain maximum distance beyond which the water cannot be circulated economically. As the

number of dwellings to be served increases, the cost of circulating the water also increases, reaching a point where it offsets the gains made possible with the heat pump. This limit is reached before the number of dwellings served approaches that which can be supplied from a single large central station. Calculations show that the size of the plant should be of the order of 20,000 kw or less.

Natural Steam Plants in Italy

Giuseppe Donata of Ercole Marelli & Co. was the author of a paper entitled "The Boric Fumaroles of Larderello and Its Natural Steam Power Plants" in which he described industrial uses of superheated steam confined underground in an area of 77 square miles located near Florence. The fumaroles, which are vents allowing gaseous products to emanate from a volcanic cone, have some similarity to geysers and give off steam almost continuously. The temperature ranges from 290 to 400 F, and the pressure varies between 71 and 390 psi. Most of the wells in the Larderello region are from 1000 to 2000 ft in depth. At the beginning of World War II there were more than 140 wells with a total steam production of 4,400,000 lb per hr. The Great Fumarole No. 1 produces about 500,000 lb of steam per hour at 50 psi and 400 F, and there are others having outputs in excess of 300,000 lb per hr.

The natural steam may be used directly in reaction-type turbines or it may be put into heat-exchangers which supply steam to condensing turbines. In some of the plants non-condensing turbines rated at 3000 to 3500 kw were installed, using the natural steam directly and exhausting to an adjoining chemical plant. A new central station which also uses the natural steam directly has just been completed. It has four condensing turbines, each having a maximum capability of 26,000 kw and a water rate of 21 lb per kwhr. Inlet steam conditions are 55 psig and 365 F.

Fuel Burning Equipment

"Fuel Availability and Its Influence on Boilers and Burning Equipment" was the topic of a paper by **P. R. Loughin** of The Babcock & Wilcox Co. Although boilers are being designed to handle a wide range of fuels, no installation will operate satisfactorily with all fuels. Prediction as to those which are to be burned during the life of the equipment becomes of importance in selecting boilers.

Diversification in burning of fuels has been made more important because of wartime restrictions and changes in the relative economic values of fuels. The increased cost of fuel and labor has also resulted in the need to burn efficiently various fuels formerly considered as byproducts or waste. In the paper industry more stringent stream pollution laws cause companies to be interested in burning waste liquor, at the same time obtaining chemical and heat recovery.

Impurities in fuels deserve special attention. The designer should have specific information on the quantity and properties of ash. Refractories and metals at elevated temperatures are susceptible to attack by ash. Sulfur also plays a part in slagging problems as well as in low-temperature corrosion. Ash and sulfur contents are both important factors affecting heat-absorbing-surface fouling and ash disposal.

Discussion

Messrs. Kuhn, Carsey and Gusler were asked about burning dry wood waste and controlling overfire air. Air jets located below the point of firing are controlled in proportion to the wood fired. Only a small portion of combustion air comes from these jets, the remainder entering through the grate.

Mr. Weigel was queried about problems of feeding wet wood and reported that no difficulties had been experienced with the rotor feeders of spreader stokers. Sand carried in with the wood causes no combustion problem, and tube erosion can be avoided by keeping gas velocities low. Rapid strides have been made in burning wood so that efficiencies are now nearly as high as with pulverized-coal firing.

Regarding multi-fuel firing when one of the fuels is difficult to light off, Mr. Decker indicated that a small quantity of fuel oil should be burned to insure safety of operation. One engineer reported that large utility installations in Texas, where fuel oil and natural gas are the dominant fuels, are being designed for future solid fuel firing. Slagging problems with heavy fuel oil were discussed, and sodium sulfate was mentioned as a substance which may be as much a cause of corrosion problems as vanadium, to which many difficulties have been ascribed.

Comments on Mr. Hackett's paper on mercury plant operation dealt with control problems and rehabilitation of the 20,000-kw unit at Kearny Station. The interesting thing from the control viewpoint is that control is obtained by varying mercury pressure to maintain plant load rather than holding constant mercury or steam pressures, as in conventional plants. In the Schiller Station telemetering is used to transmit information to the central control board. At Kearny it was reported that furnace tubes which had wasted away over a ten-year operating period were faced with a coating of 18-8 stainless steel.

The application of the heat pump in conjunction with the gas turbine was mentioned. This was studied but not believed to be economical because the exhaust gases consist largely of sensible heat, whereas latent heat is available in condensing water. The feasibility of having a large heat pump at a central station was also discussed.

Concerning Mr. Loughin's paper on fuel burning it was pointed out that the South is very much interested in multi-fuel firing and particularly in conversion of existing boilers to burn natural gas. Problems of adapting underfeed stokers to gas firing were mentioned by several persons.

Discussion of the paper on natural steam plants revealed that another natural steam field had been discovered and is being developed in Chile.

Corrosion Conference Held in New York

THE Seventh Annual Conference and Exhibition of the National Association of Corrosion Engineers was held in the Hotel Statler, New York City, on March 13–16. Nearly 1300 persons were registered for the technical sessions and the extensive exhibits of products relating to prevention of and protection against corrosion. Of special interest to engineers in the steam power field was a symposium on boiler feedwater which was co-sponsored by the Subcommittee on Corrosion of the Joint Research Committee on Boiler Feedwater Studies.

The first paper of the symposium was entitled "Prevention of Corrosion and Metal Attack in the Steam Water Cycle of the Steam Power Plant" and was presented by **Prof. Frederick G. Straub** and **Harry D. Ongman** of the University of Illinois. Unless metallic products which are picked up in the preboiler cycle of the steam power plant are removed in blowdown, they accumulate in the boiler. The forms in which they enter the boiler and their distribution within the boiler may be the explanation of corrosion and metal attack taking place within the boiler.

Laboratory Tests

The authors described a series of tests at the University of Illinois to determine the solubility of copper and iron in a flowing stream of gas-free, deaerated high-quality distilled water. Results indicate that distilled water containing oxygen and carbon dioxide will pick up iron but will not materially change the pH of the water. When the distilled water is deaerated to remove the oxygen and carbon dioxide, the pickup of iron is accompanied by an increase in pH to a value of about 9.1. When sodium hydroxide is added to the distilled water so as to have the pH above 9.1 before passing the gas-free water through the iron, there is a very marked decrease in the iron pickup. The same result is shown even in the presence of oxygen.

Similar tests were conducted in which distilled water was passed through a copper pipe at room temperature and the copper pickup determined. A sample of undegassed distilled water passed through the copper tube showed a high pickup of copper with an end pH of about 7. Degassed water showed a much lower copper pickup with the same end pH. When sodium hydroxide was added to the degassed water so that the pH was 8.8 there was no copper in the water leaving the copper tube. This was also the case when ammonia was added to degassed water, in two tests, in which the pH reached 8.7 and 7.7 respectively.

One study was reported of a central station in which a large amount of iron sludge was found in the boilers. The station operates at 900 psig on a condensing cycle with evaporated makeup. Ammonia content of condensing water and water used in the evaporators was low. The pH of the steam was also low, but the value increased in passing through the cycle to the condenser and the boiler feed pump. The iron increased as the steam and condensate passed through the cycle, while the ammonia remained low and constant, indicating that iron was being dissolved as ferrous ion and was increasing the pH of the water. In an attempt to remedy this condition ammonia was added to the system as ammonium chloride. As the ammonia concentration was built up the pH of the steam increased and the iron pickup decreased. When the pH of the steam reached a value around 9.0 the iron pickup dropped to a very low value, as did the copper pickup.

In another central station ammonia has been used for a similar purpose since September 1947. Examination of the boilers during annual inspection has shown the iron and copper sludge to be reduced to an extremely small amount.

Reducing chemicals such as sodium sulfite may also aid in cutting down the amount of copper and iron which might enter the boiler in the higher state of oxidation. When the sulfite concentration is high enough in the boiler water, the oxides are reduced prior to reaching the boiler heating surface, to which they also become less adherent.

There are conditions of operation which appear to limit the amount of sulfite residual which may be carried in a boiler without liberating sulfur dioxide or hydrogen sulfide in the steam. The presence of ammonia in the steam to maintain the desired pH will neutralize the acid effect of the sulfur dioxide.

Amount of Iron Oxide Determined by Chemical Cleaning

The second paper in the Boiler Feedwater Symposium was by **M. E. Brines** and **F. N. Alquist** of the Dow Chemical Company, who discussed "Iron Oxide on Water Side of Tubes in a Cyclone-Fired Pressurized Steam Generator." The study is concerned with the quantity of iron oxide in such a unit during the first five months of operation. It has a rated capacity of 400,000 lb per hr of steam at 1250 psig, 850 F and operates with 100 per cent makeup of demineralized water. Heat release in the cyclones is 545,000 Btu per cu ft per hr, while the average heat release for the entire furnace is 32,300 Btu per cu ft per hr.

The design of the boiler was adapted to facilitate chemical cleaning so that any of the following sections may be chemically cleaned independently of the rest of the unit should this become necessary because of localized deposition:

1. Primary and secondary furnaces up to the top cyclone headers.

2. Primary economizer.
3. Primary and secondary economizers.
4. All surfaces in contact with boiler water.
5. Superheaters and attemperator.

As soon as the erection of the boiler was completed, the first chemical cleaning was carried out on the following schedule:

1. The boiler was filled with water which was kept at 175–200 F overnight.

2. This water was drained and replaced by 22,550 gal of 3.5 per cent inhibited hydrochloric acid at 175 F.

3. After being in the boiler for five hours the acid was drained out and replaced at the same time with water, a procedure which continued until the concentration dropped to less than 0.5 per cent acid. The boiler was then drained, refilled with deaerated water containing 2000 lb of soda ash and boiled at 25 to 50 psig for two hours. The soda ash solution was replaced with water by filling and draining at the same time for one hour.

The boiler was operated for a period of three months and then acid cleaned again. The procedure was similar to the first chemical cleaning except that 10 per cent acid was used and the superheater was blanked off. Drain samples of acid were obtained and analyzed, five of which averaged 0.56 per cent iron for the 18,550 gal of solvent used. This amounts to 900 lb of iron, and calculations were made to show that 22 lb were attributable to acid corrosion, 220 lb to ferric ion reduction and the remaining 658 lb to solubility of Fe_3O_4. Assuming equal distribution of the equivalent 908 lb of Fe_3O_4 over 6000 sq ft of boiler surface, 0.15 lb of this material was removed per sq ft of surface. This is equivalent to a 0.005-in. coating over the metal.

Nearly two months later the boiler was chemically cleaned for the third time. A two-stage treatment was used in which 6 per cent solvent was allowed to remain in the boiler for a four-hour soaking period. The acid was drained and replaced with new solvent which was allowed to remain for six hours, after which the boiler was emptied and soda ash added as in the first two cases.

This time 878 lb of iron were dissolved, of which 636 lb were due to the solubility of Fe_3O_4. The calculated equivalent of Fe_3O_4 was found to be 877 lb. Assuming equal distribution of this material over 6000 sq ft of boiler surface, the amount removed was again determined to be 0.15 lb Fe_3O_4 per sq ft.

The authors offered the following principal conclusions:

1. The corrosion of the water side of the tubes of a steam generator leads to formation of iron oxide deposits during start-up operations.

2. By means of chemical cleaning the amount of iron in this film, on two occasions during the first five months of operation, was found to be 658 and 636 lb, which is equivalent to 908 and 877 lb of iron oxide.

3. The iron carried into the unit by the operating feedwater system was two pounds per day for the 400,000 lb per hr of water used.

Protection of Idle Boilers

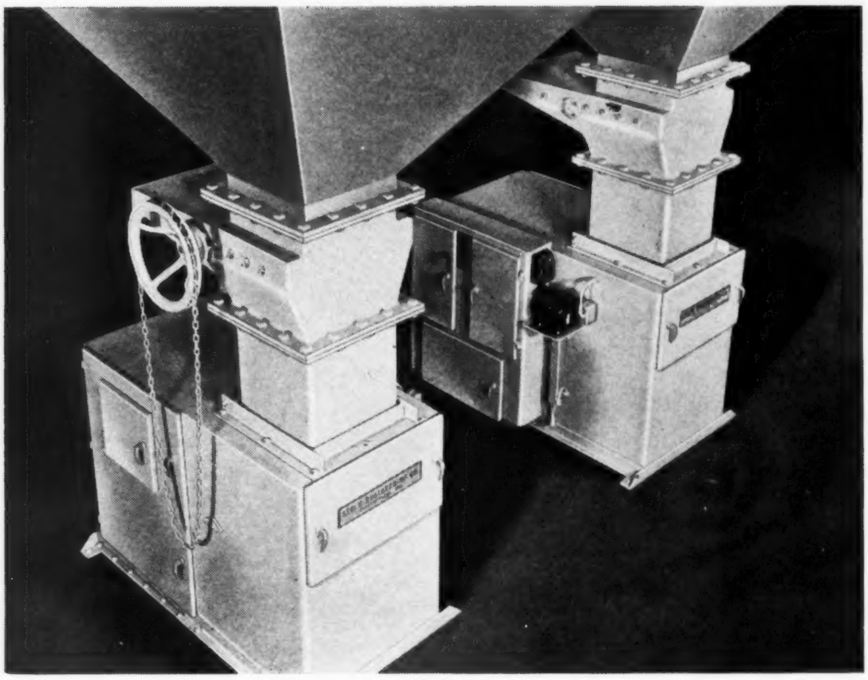
"Prevention of Stand-by Corrosion in Power Plants" by **Leonard Highley, Jr.,** and **W. R. Schnarrenberger** of Hall Laboratories, Inc., was the third paper in the symposium. When equipment is idle it may be more difficult to prevent corrosion than under normal conditions of operation. Ordinarily it is impossible to differentiate between operational and stand-by corrosion simply by visual or metallographic examination in the laboratory. The history of the operation and the water conditions maintained must be known to aid in this differentiation.

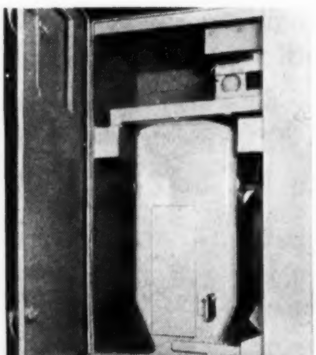
Sometimes boilers are maintained in wet stand-by. When they cool the internal pressure drops, creating a partial vacuum, and all of the space normally occupied by steam becomes filled with air. The metal exposed to the moist atmosphere in these regions is extremely vulnerable to corrosive attack stimulated by oxygen and carbon dioxide. The problem of preventing such corrosion resolves itself into eliminating either the moisture or the oxygen. Occasionally, due to climatic conditions, external corrosion is troublesome. This attack can be expected almost any place on the furnace side of tubes where condensation may occur. The presence of soot and ash accumulations containing sulfur compounds may increase the corrosion.

Under conditions of intermittent stand-by, water level corresponds closely to that of operation. Circulation is slight and there may be some loss of water through leaking blowdown valves or by light steaming. This loss must be replaced by feedwater, which in turn may result in segregation producing conditions of low alkalinity and dissolved oxygen at some boiler surfaces and making them susceptible to corrosion. In some cases where stand-by is for a considerable period and appreciable makeup is required for losses, the boiler water alkalinity may disappear entirely and general corrosion may occur.

For prolonged stand-by the boiler may be emptied, dried out and kept dry. With non-drainable superheaters it is recommended that warm air be blown through individual tubes or elements for initial drying. To insure complete drying and elimination of subsequent condensation, a series of small heaters should be installed in the furnace at the lower extremity of the superheater bank. This represents the most positive means of minimizing stand-by corrosion in the superheater. If there is evidence of external sweating of boiler tubes, additional heaters should be installed in the furnace at strategic locations to maintain temperatures above the dew point.

On the other hand, the wet method gives good protection provided: (1) the correct chemical conditions are maintained in the water with which the boilers are filled; (2) mixing is such that fairly uniform concentrations are obtained throughout the boiler; and (3) the boilers are completely filled with treated water. Sufficient caustic soda should be added to give a sodium hydroxide concentration of 250–400 ppm and also enough sodium sulfite to hold a concentration of 100 ppm or even higher. These concentrations are higher than in





normal operation, but the margin of safety is needed due to the possibility of greater oxygen contamination. Samples from various sections of the boiler should be tested periodically to determine whether or not the concentrations of alkalinity and sodium sulfite are satisfactory.

Corrosion of Underground Structures

"Cathodic Protection of Steam-Electric Generating Stations" was the title of a paper by **J. H. Collins** and **E. H. Thalmann** of Ebasco Services, Inc. Their discussion centered about corrosion of underground structures, applications of cathodic protection and testing procedure. Piping, cable sheaths and other structures at electric generating stations are solidly connected to the station grounding system, which generally is an extensive grid of heavy bare copper cable and ground rods. The resulting galvanic cell is an important factor in corrosion, particularly when the structures are in low resistivity soil.

Current requirements for cathodic protection range from 50 amperes to several hundred amperes, supplied from rectifiers and graphite-anode, coke-breeze ground beds. The choice of ground bed locations is restricted by the need of avoiding proximity to underground structures. The station grounding system generally is connected to transmission line shield wires or counterpoises, or to transmission cable sheaths which take a part of the cathodic protection current. Precaution to avoid shock hazards during power faults is necessary in isolating incoming pipe lines. Pronounced shielding effects result from large pipe lines, multiple cable runs and reinforcing steel in concrete mats.

Testing procedure includes checking continuity of the grounding system and tests of current distribution, potential changes and polarization effects to determine protection. Circulating water intake screens, spillway gates and other isolated structures require separate additional protective installations.

Use of Filming Amines

H. Lewis Kahler of the W. H. & L. D. Betz Co. presented a paper entitled "Field Results on Condensate Line Corrosion Prevention with the Filming Amines" which covered a period of three years of operating experience. The experience of a number of plants indicates that an 80 to 99 per cent reduction is obtained in the rate of carbon dioxide corrosion of steam and condensate return lines. When filming amines were first used in the field after pilot-plant tryouts, unexpected difficulties were encountered which were later overcome when a suitable chemical test for amines was developed and a change was made in the method of feed.

There were two principal problems encountered in the initial use of the filming amines under full scale plant conditions. The first was the necessity for dispersing the amines in ion-free water in order to avoid precipitation of the insoluble chloride and sulfate of the amines in the feeding system. In the second place it was found that the amines removed iron oxide deposits from previously corroded surfaces. By using less treatment at the start and increasing the normal amount over the

first few months, it was noted that the filming amine treatment, in a period ranging from three months to a year, had cleaned the surfaces of most of the old corrosion products and laid down a protective film.

The use of corrosion test specimens exposed throughout the return line system has proved a reliable guide to the progress of amine treatment in minimizing corrosive attack. A standard test specimen, specimen holder and condensate-line bypass have been employed. Data secured from exposure of corrosion test specimens before and after amine treatment were presented for a number of plants.

Defends Delays Under Nationalized Power Supply

Your first editorial of the January issue is unfair to Nationalization. The many consents preliminary to power plant construction in Britain are the product of planning. This may be thought good or bad. It depends partly on your political views and partly on where you live and work. We find that a farmer who is to be dispossessed of his land and livelihood by power station construction thinks it a good idea to have the Ministry of Agriculture satisfied that there is no alternative. Similarly local residents are all in favor of an Authority independent of the electricity industry being satisfied at a public inquiry that all reasonable precautions are being taken against smoke, grit and coal dust nuisances, and that the plant planned will not be gratuitously ugly.

From my experience of the United States, most power plant designers there voluntarily accept most of the public obligations that are laid upon us. But it is easier for them than for us, because Britain is a very crowded piece of earth. I believe there are pulverized fuel stations in the United States with no arrestors or precipitators. We could not think of distributing over the countryside what our precipitators collect, for it is obviously intolerable here.

Where we have to improve our technique is in streamlining the obtaining of the consents to construction. We have improved in this matter somewhat in the past year or more, by method and motion study. You would be the last to decry that intelligent planning which allows you to get a plant into existence so quickly. It is not politics that cramps our style, so much as economics. With a given capital equipment of factories, a given essential export trade by which to feed us, and growing armies, one cannot see that the influence of ownership of power plant on the rate of extending it is very important.

Therefore, without denying the marked contrast between post-war power construction in the United States and in Britain, and without expressing any opinion on political theories, I do emphatically deny that nationalization has had an adverse effect on progress. I say this after two years as a Chief Generation Engineer (Construction) at the heart of the business of planning and construction in Yorkshire Division.

W. H. DUNKLEY, *Chief Generation Engineer (Construction)*

Obituaries

Dr. Charles E. Lucke, professor emeritus of mechanical engineering at Columbia University and well-known authority on thermodynamics and internal-combustion engines, died at St. Luke's Hospital, New York, on March 25. He was 74 years old and had become a member of the Columbia faculty in 1902, even continuing to give special lectures after retirement.

Dr. Lucke held the rank of commander in the Navy during World War I and over the years had served as consultant to many industrial companies, as well as to the Brookhaven National Laboratories and the National Advisory Committee for Aeronautics.

Frank A. Chambers, head of Chicago's Department of Smoke Inspection and Abatement and for many years secretary of the Smoke Prevention Association of America, died of a virus infection on March 21. Shortly after his graduation from Armour Institute of Technology in 1906, he became associated with this department and became its head in 1912.

William L. Abbott, past president of the ASME and from 1899 to 1935 chief operating engineer of the Commonwealth Edison Company, Chicago, died on February 20. He had been in retirement since 1935 after a career of 50 years in the electric power industry. He was a graduate of the University of Illinois.

Business Notes

Westinghouse Electric Corp. has named Robin S. Kersh manager of its Steam Division at South Philadelphia. He was formerly manager of central station sales.

Edward Valves, Inc., East Chicago, Ind., has appointed Bruce K. Stabelfeldt advertising and sales promotion manager.

General Electric Co. has appointed Ralph E. Donnelly manager of its Fitchburg, Mass., turbine sales division.

The Philip Carey Mfg. Co., Cincinnati, has recently made L. C. Underwood assistant advertising manager. Since 1947 he had been engaged in sales and promotional field work for the company.

Bigelow-Liptak Corp. has appointed Victor P. Johnson to its sales staff in New York. Mr. Johnson was formerly with the M. W. Kellogg Co.

Cochrane Corp., Philadelphia, announces that S. B. Applebaum will take over management of its Water Treatment Division. Mr. Applebaum, who has specialized in water conditioning for more than 35 yr, joined Cochrane in 1949.

Hagan Corp., Pittsburgh, has named two veteran employees to its board of directors. They are R. R. Donaldson, who joined the company in 1919 as a service engineer, and Dr. Everett P. Partridge, who joined Hall Laboratories in 1935 as research director.

National Aluminate Corp., Chicago, has named Joseph A. Holmes a vice president. He has been with the organization since 1924.

De Laval Steam Turbine Co., Trenton, N. J., has appointed Patrick J. Patton Milwaukee manager for handling the sales of turbines, pumps and blowers in Wisconsin. His headquarters will be in Wauwatosa, Wisc.

Wright Chemical Corp., Chicago, has appointed Charles W. McCumber St. Louis district manager, with headquarters in St. Louis. He will be in charge of all Wright water-conditioning sales representatives in Missouri, Arkansas, Tennessee, Kansas and the southern half of Illinois.

Hawkins-Hamilton Co. of Charlotte, N. C., has been appointed district representative of the **Vulcan Soot Blower** and **Northern Equipment Divisions** of the Continental Foundry and Machine Co. For the former it will handle Vulcan soot blower systems and for the latter, Copes regulators, differential valves, pump governors, reducing valves, desuperheaters, liquid level controls and allied equipment.

The Swartwout Co., Cleveland, O., has established a new sales office at 836 Michigan Theatre Bldg. in Detroit.

Johns-Manville Corp. has named William R. Wilkinson vice president in charge of sales and Kenneth W. Huffine vice president for production.

New Expediting Set-up

Combustion Engineering-Superheater, Inc., New York, has inaugurated a new plan of customer service designed to minimize present-day difficulties in maintaining schedules to meet project requirements and in keeping customers fully and promptly informed as to the status of their jobs.

Because salesmen are advantageously situated to keep in close touch with their customers' problems, one salesman in each distrct has been given the full-time assignment of acting as a special liaison between customers in his territory and the contract, production and purchasing departments in New York. One of the Company's district managers has been brought into New York to act as a production coordinator and supervise the work of this special field squad.

It will be the field man's responsibility to keep in constant touch with customers in his district so that he may promptly relay to New York any changes in their projects which might affect the Company's scheduling, production or shipment. On the other hand, he will advise the customer immediately if the latter's job is subject to delay because of incomplete information or other circumstance which the customer might be able to rectify.

In this way the execution of contracts can be coordinated with a customer's real needs and the general progress of his project from week to week, and shipments can be timed to gear in with the development of the project as a whole. The field man will also serve the Company's purchasing department by acting as an expediter on materials and equipment purchased from suppliers in his district.